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(54) Title: **MEMBRANE EXPRESSION OF HETEROLOGOUS GENES**

(57) Abstract

The invention relates to pharmaceutical compositions and methods of producing bacterial host surface-expressed heterologous polypeptides useful in the preparation of vaccines, and particularly oral vaccines for prophylaxis of diseases associated with cholera, human immunodeficiency virus, influenza virus, and rickettsial infections.

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DESCRIPTION

MEMBRANE EXPRESSION OF HETEROLOGOUS GENES

BACKGROUND OF THE INVENTION

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Field of the Invention

The invention relates generally to the field of vaccine development, and particularly to pharmaceutical compositions comprising oral vaccines effective against bacterial and viral diseases such as cholera, rickettsia, influenza and human immunodeficiency virus. In certain aspects, the invention relates to methods of treating these diseases through oral administration of attenuated bacterial strains comprising surface-expressed heterologous polypeptide immunogens.

Description of Related Art

20 Recombinant gene technology has been extensively investigated in the context of expression of foreign proteins from recombinant host cells, typically bacterial host cells. Such expression is desirable for producing high value proteins, immunogenic polypeptides, and in 25 obtaining hybrid proteins that are otherwise difficult to synthesize.

30 Isolated epitopes of known antigens of eukaryotic, viral and prokaryotic pathogens are recognized as potentially useful in vaccine development. Preparation of protective vaccines from transformed host cells has been attempted. Oral vaccines have stimulated interest because of the ease of administration and, more importantly, in some instances the unsatisfactory 35 protection afforded from parenteral injection.

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While vaccination against cholera has been possible, the effect has been short-term, necessitating the development of longer-term therapies. Sanchez et al. (1990) have proposed a possible approach to the problem 5 through the development of an oral vaccine that would presumably stimulate mucosal intestinal immunity more efficiently. However, no oral vaccine against cholera has been developed which is completely effective.

10 1. Cholera Toxin

Cholera toxin (CT) is an exotoxin produced by *V. cholerae* and is composed of one A subunit (CTA) and five B subunits (CTB) (Holmgren, 1981). The A subunit is a 27 15 kDa protein which is responsible for enterotoxigenic activity, mediates the ADP-ribosylation of adenylate cyclase (Field, 1971), and induces the release of eicosanoids (Peterson and Ochoa, 1989). The B subunit is a homopentamer consisting of 11.6 kDa subunits (Holmgren, 20 1981). The primary amino acid structure of CTB (Kurosaki et al., 1977) and the complete sequence of the *ctxB* gene (Mekalanos et al., 1983) have been determined. The B subunit functions to bring the enzymatic A subunit in contact with the cell through high affinity binding to 25 GM1 ganglioside which is present on the cell surface (Holmgren, 1981). GM1 ganglioside is widely distributed in the cell membrane of mammalian cells (Holmgren, 1981). Hence, possibly through the ubiquitous nature of its receptor, CT can modulate the activity of a variety of 30 cells. These include not only those directly involved in the cholera diarrheal secretory process, but also cells of the immune system, including lymphocytes and antigen-presenting cells (APC) (Holmgren and Lindholm, 1976). For many of these activities, CTB shares the same 35 properties with the holotoxin (Elson, 1989).

The cholera toxin A and B subunit proteins are tandemly arranged as a single transcriptional unit (Mekalanos et al., 1983). Oxidation of B subunits during export from the cytosol is a prerequisite for 5 pentamerization (Hardy et al., 1988). The B subunit enters the periplasm as a monomer and is assembled into oligomers prior to secretion (Hirst and Holmgren, 1987). Thus, CTB is present in multiple molecular forms in bacterial cells.

10

## 2. Host Immune Response to Cholera Toxin

The host immune response to CT has been extensively studied. It is generally accepted that protective 15 immunity against cholera is dependent on the stimulation of the immune system of the gut. Secretory IgA production (sIgA) in response to locally encountered antigens (Svennerholm et al., 1984; Hanson and Brandtzaeg, 1986; Holmgren and Lycke, 1986) is believed 20 to play a major role. Both antibacterial and antitoxic mucosal immunity are observed after natural infection (Holmgren and Svennerholm, 1983) and are associated with protective states. Neutralization of CT by CTB-specific antibodies effectively abrogates CT activity in animal 25 models (Holmgren, 1981; Svennerholm et al., 1984). Antibodies raised to denatured CTB or toxoid are also effective at neutralizing CT activity (Markel et al., 1979).

30 Local intestinal immune responses are thought to be initiated by antigen uptake mechanisms of specialized epithelial M cells (Pierce and Koster, 1981; Cebra et al., 1976; Husband and Gowens, 1978). For *Salmonella*, penetration of the epithelial lining of the gut, and 35 residence in the lamina propria may also initiate the immune response. Antigens are processed by macrophages, and then presented to immunocompetent T and B cells.

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There is evidence for the activation of antigen-specific helper T cells and B cells from Peyer's patches (PP) (Elson and Ealding, 1984; Husband and Gowens, 1978; Fuhrman and Cebra, 1981). Stimulated-B cells and 5 possibly T cells migrate to the mesenteric lymph nodes (MLN). Cells are then distributed to different lymphoid tissues and all mucosal sites. A population of committed cells home to the intestinal mucosa, where development to differentiated effector cells occurs. Thus, intestinal 10 immune responses can produce a systemic response and antigen-specific lymphoid cells at all mucosal sites.

There is some indication that the optimal means of stimulating the secretory immune system of the gut is by 15 locally applying the immunogen. Evidence exists which indicates that live oral avirulent *Salmonella* vaccines may be effective in priming the local immune system; however, no studies have shown such priming would be useful in generating an immune response against other 20 unrelated pathogens. Thus the development of oral vaccines which utilize *Salmonella*-induced immune system priming against such unrelated pathogens would constitute a major breakthrough in the field of oral vaccine development.

25

### 3. *Salmonella* as a Candidate for Oral Live Vaccines

*Salmonella* strains have been studied as particularly attractive candidates for producing oral live vaccines. 30 Attenuated strains have elicited immune responses in several animal species (Strugnell et al., 1990) and apparently can be highly immunogenic in the host. Humoral antibody responses as well as local secretory antibody and cellular immune responses have been observed 35 after oral intake (Dougan et al., 1986). Attenuated mutants have been identified via screening procedures such as *TnphoA* insertions, that permit elimination of

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mutations in nonsecreted proteins (Miller et al., 1989). However, TnphoA methods only indicate assessment of integration of the transposon into a gene for a secreted or cytoplasmic protein.

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Local intestinal immune responses are thought to be initiated by antigen uptake mechanisms of specialized epithelial M cells (Pierce and Koster, 1981; Cebra et al., 1976; Husband and Gowens, 1978). For *Salmonella*, 10 penetration of the epithelial lining of the gut, and residence in the lamina propria may also initiate the immune response. Antigens are processed by macrophages, and then presented to immunocompetent T and B cells. There is evidence for the activation of antigen-specific 15 helper T cells and B cells from Peyer's patches (PP) (Elson and Ealding, 1984; Husband and Gowens, 1978; Fuhrman and Cebra, 1981). Stimulated-B cells and possibly T cells migrate to the mesenteric lymph nodes (MLN). Cells are then distributed to different lymphoid 20 tissues and all mucosal sites. A population of committed cells home to the intestinal mucosa, where development to differentiated effector cells occurs. Thus, intestinal immune responses can produce a systemic response and antigen-specific lymphoid cells at all mucosal sites.

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Surprisingly, little is currently known as to the subcellular placement of a recombinant antigen in an avirulent *Salmonella* strain on the nature of the immune response which is elicited. In this regard, antigen 30 placement may have a profound effect on the quantitative and qualitative aspects of the immune response directed to a recombinant antigen. For example, a recombinant circumsporozoite (CS) antigen expressed cytosolically in *Salmonella* has yielded high levels of cell-mediated 35 immunity with virtually no detectable humoral response (Sadoff et al., 1988). In contrast, the immunodominant epitope of the CS antigen expressed in a recombinant

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flagellin protein on the *Salmonella* surface produces an antibody response (Majarian et al., 1989). Thus, the location of an antigen, inside the bacterial cell versus on the surface of the bacterium, appears to influence the 5 nature of the immune response.

#### 4. Protein Expression Systems in *Salmonella* sp.

Protein expression systems have been developed from 10 *Salmonella* strains. A cloning vector useful for integrating DNA into the *Salmonella* chromosomal *aroC* gene has been used to express heterologous antigens such as tetanus toxin fragment C and *Treponema pallidum* 15 lipoprotein (Strugnell et al., 1990). In some cases, heterologous polypeptide gene products orally administered have elicited a serum antibody response; for example, the heterologous cholera toxin B subunit protein expressed from a recombinant *Yersinia enterocolitica* strain (Sory and Cornelis, 1990). Unfortunately, while 20 antibodies were detected in sera of inoculated mice, the response was variable and was directed toward polymeric forms of cholera toxin B.

It is recognized that antigenic proteins may not 25 produce a strong immunogenic response, possibly because of masking of epitopic regions. Likewise, potential antigens expressed as heterologous proteins from recombinant host cells often lack antibody reactivity (Sanchez et al., 1990). It is believed that even minor 30 modifications of a given antigenic region may lead to complete sequestering of an epitope. While surface expressed epitopes of bacteria may be expected generally to elicit the greatest humoral response, factors controlling surface expression of heterologous proteins 35 have not been defined and there is no way to assure that a fusion protein will localize to a host cell membrane surface.

Despite disappointing results in effecting immunity, the use of attenuated *Salmonella* strains to express heterologous antigens and stimulate GALT is being 5 extensively investigated. In some studies, detectable levels of specific mucosal and serum antibodies to the heterologously expressed antigen have been observed (Black et al., 1987; Curtiss et al., 1987; Dougan et al., 1986; Dougan et al., 1987). However results with most 10 antigens have generally been variable. Humoral response to *Salmonella*-expressed *E. coli* K88 fimbriae (Dougan et al., 1986) and  $\beta$ -galactosidase (Brown et al., 1987), as well as humoral and secretory responses to the 15 *Streptococcus* mutants GFT A polypeptide (Curtiss et al., 1986) and *Shigella* type and group antigens (Black et al., 1987) have been reported. Thus, while these studies have established the utility of *Salmonella* expression of 20 heterologous antigens in generating a specific immune response, and while significant specific mucosal and serum responses to some antigens have been observed, the nature and extent of immune responses to other expressed 25 antigens have been variable. The export of heterologous antigens to the cell surface may enhance their interaction with the immune system (Fields, 1986) possibly through enhancement of T cell-independent mechanisms.

Investigators have expressed heterologous epitopes 30 as inserts in surface-expressed *Salmonella* flagellin or *lamB* protein. Flagellin with inserts specifying a CTB subunit epitope (Jacob et al., 1983; Newton et al., 1989), a hepatitis B surface polypeptide epitope (Wu et al., 1989), and M protein epitopes (Newton et al., 1990) have also induced a humoral response. *Salmonella*-expressed *lamB* hybrid genes expressing VPI epitopes of 35 polio virus (Charbit et al., 1988), pre-S2 of hepatitis B (Charbit et al., 1987), and HIV epitopes (O'Callaghan

et al., 1990) yielded similar results. Significant limitation of these systems include: 1) the relatively small number of epitopes which can be inserted into these gene hybrids; and 2) the relatively small size of DNA 5 insert possible in the flagellin fusions.

### 5. Deficiencies of the Prior Art

10 The relatively poor and vague understanding of the immune response to the placement, conformation and processing of bacterial-based antigens which lead to secretory, humoral or cell-mediated immune responses, has provided little information concerning the issue of subcellular placement of antigens and their corresponding 15 effects on the immune response. Previously, evaluating the antigenicity of the same molecule in various subcellular locations has been technically difficult. In spite of limited knowledge in this area, recombinant-based antigen placement vectors have been developed 20 (Curtiss et al., 1989) which "place" recombinant antigens in the periplasm, membranes, or within surface structures (i.e. flagella), or which secrete these molecules.

25 Although studies have demonstrated some aspects of immune responsiveness to a few antigens, no studies have addressed various subcellular placements of the same antigen on the immune response. There is clearly a need to develop effective systems to elicit antibody response and in particular to provide methods of exporting 30 heterologous polypeptides to the surface of appropriate host cells.

SUMMARY OF THE INVENTION

The present invention overcomes the deficiencies in the prior art by providing novel compositions and methods 5 for the production of oral vaccines comprising *Salmonella* surface-expressed heterologous immunogenic polypeptides.

The invention also includes nucleic acid segments useful for preparing expression vectors which encode 10 these heterologous polypeptides. Such vectors are suitable for transforming host cells to produce heterologous polypeptides exported to selected areas of the host cell.

15 The nucleic acid segments of the present invention encode amino acid sequences associated with targeting of fused heterologous polypeptides to specific areas of a transformed host cell. It has been found for example that nucleic acid segments defined by SEQ ID NO:1 encode 20 a polypeptide product that when fused to a heterologous polypeptide will direct that polypeptide to the outer membrane of a bacterial cell. By heterologous polypeptide is meant any polypeptide other than those normally associated with the peptide encoded by SEQ ID 25 NO:1. It is of course understood that such localizing capabilities are realized under conditions when the exportation polypeptide is incorporated into a suitable expression vector and an appropriate cell host is transformed with that vector. A preferred embodiment of 30 the DNA segment defined by SEQ ID NO:1 encodes a 50 kDa polypeptide with surface-directing properties.

The present invention also includes nucleic acid segments encoding amino acid sequences associated with 35 the transport of heterologous polypeptides to a bacterial inner membrane periplasmic space. Particular embodiments of the present invention includes the nucleic acid

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sequence of SEQ ID NO:2. This sequence encodes a 63 kDa preferred inner membrane/periplasmic space-directing polypeptide. This preferred embodiment includes gene sequences encoding part of the APase gene, however, other 5 heterologous genes may be used in place of APase.

While particular nucleic acid sequences have been defined, it is nevertheless contemplated that nucleic acid sequences will be found to vary. It is expected 10 that analogous sequences with similar functions may be found in other gram-negative bacteria such as *E. coli* or other bacteria having homology with *Salmonella* such as those bacteria with 40% or greater homology.

15 More distantly related or unrelated sequences which provide an analogous function could be found in gram positive bacteria such as the enterococci, *Listeria monocytogenes*, *Corynebacterium* sp., *streptococcus* species, and anaerobic bacteria such as *Clostridium* species. Also, *Neisseria* sp., mycoplasma species and 20 *Vibrio* species and *Yersinia* species especially *Y. enterocolitica* are Gram-negative bacteria in which sequences of similar function could be found.

25 It is also anticipated that analogous sequences could be found in yeast such as *Saccharomyces* and others which could be used for the same purposes. Eucaryotic cells such as those which can be propagated in tissue culture and analogous export-directing sequences are 30 anticipated to be able to perform similar functions. Insect cells such as those commonly used to propagate *Baculovirus* and their recombinant derivatives would also be imagined to function in these methods.

35 In certain particular embodiments, the invention concerns expression vectors that are constructed to include any of the DNA segments herein disclosed. Such

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DNA may be fused directly with a gene of interest and used in an expression system to produce heterologous polypeptides as hybridization probes for, e.g., identifying related sequences, as primers, or even as 5 building blocks for the construction of mutant or variant sequences. A particularly useful application of the DNA segments of this invention is to achieve directed expression of heterologous polypeptides. Depending on the DNA segment selected, polypeptides will be expressed 10 on the periplasmic face of the inner membrane, associated with the outer membrane of the host cell, or on the surface of the outer membrane of the host cell.

In a particular embodiment, pZIP plasmids have been 15 constructed. Depending on the plasmid selected, fusion polypeptides are exported to the periplasmic face of the cytoplasmic membrane or to the outer membrane of the host cell. In a preferred embodiment, pZIP-OUT directs the export of fusion polypeptides to the outer membrane at 20 the external surface of a Gram-negative host cell. pZIP-OUT is a bipartite fusion including a *Salmonella typhimurium* DNA segment capable of exporting the fusion product to the external membrane of a Gram-negative cell. The second part of the chimeric gene is an *Escherichia coli* gene encoding APase (*phoA*). This *phoA* reporter gene 25 segment lacks both regulatory and signal sequences, and the activity of the PhoA fusion polypeptide *in vitro* and *in situ* is readily monitored through the use of chromogenic substrates. A variety of DNAs or DNA 30 segments may be inserted into the *phoA* gene at suitable restriction sites to create in-frame, tripartite fusion.

Yet another preferred embodiment is pZIP-IN. This 35 plasmid directs the export of polypeptides to the inner membrane periplasmic space or the surface of the outer membrane. The construction of the plasmid is basically bipartite. Part of the APase gene lacking signal and

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expression sequences is fused with a DNA sequence that contains an exportation sequence capable of directing its fusion polypeptide to the inner membrane/ periplasmic space. There are several restriction sites in the *phoA* gene segment into which foreign DNA or fragments of DNA 5 may be inserted.

Other components of either of these plasmids may include, in addition to the export specifying sequences, 10 resistance genes such as ampicillin or tetracycline resistance genes. Additionally an *E. coli* *phoA* gene may be fused in frame with expression directing DNA sequences, such as that used to construct the pZIP-IN and pZIP-OUT plasmids. pZIP-IN additionally encodes a 15 kanamycin resistance gene. An advantage of using the *phoA* fusion is that there are various restriction sites within the *phoA* gene facilitating the fusion of heterologous gene sequences in frame with the export specifying sequences.

20

Expression vectors may also include a gene encoding a detectable polypeptide (a "reporter" gene). Typical examples of polypeptides or reporter genes encoding detectable polypeptides include those for *E. coli*  $\beta$ -lactamase and APase. Reporter genes may be conveniently fused downstream of the disclosed nucleic acid sequences with or without other DNA fragments/segments. Moreover, 25 restriction sites in the gene sequence of the detectable polypeptide may be used for insertion of a desired DNA 30 fragment(s).

Recombinant vectors such as those described are particularly preferred for transforming bacterial host cells. Also it is imagined that recombinant vectors may 35 be employed in gram positive bacteria such as the enterococci, and other streptococcal species, and in BCG or other *Mycobacterium bovis* or other *Mycobacterium*

species derived for vaccine delivery. Several types of bacterial host cells may be employed, most preferred being Gram-negative cells such as *E. coli*, *Salmonella* and the like.

5

Several avirulent *Salmonella* strains are contemplated as useful in the development of the oral vaccines of the present invention. These orally administered live attenuated vaccines induce specific 10 cell-mediated responses (CMI) and elicit secretory IgA (sIgA) (Sadoff et al., 1988; Poirier et al., 1988; Clements, 1989; Brown et al., 1987. sIgA is especially important because of its effectiveness at mucosal surfaces, sIgA production and CMI responses are mediated 15 through the interaction of antigens with lymphoid cells present in gut associated lymphoid tissue (GALT). Stimulation of GALT can lead to effective cell and humoral defense at all mucosal surfaces and provide systemic protection.

20

Recent investigations have shown superior mucosal humoral immunity and cellular immunity in animals receiving oral compared to parenteral *Salmonella* immunization (Tagliabue, 1989). Thus, *Salmonella* carrier 25 strains have a demonstrated potential in targeting specific antigens to GALT and in establishing immune states.

A number of avirulent and virulence-attenuated 30 *Salmonella* are contemplated to be useful in the methods disclosed herein. Plasmidless variants, auxotrophic mutants (*aroA*, *pur*), regulatory mutants (*cya/crp*), strains altered in carbohydrate utilization (*gale*) and others (*phoP*) have been investigated as potential carrier 35 strains (Curtiss et al., 1989). These strains can colonize and invade the gut epithelium, persist in tissue, and consistently evoke serum and mucosal antibody .

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responses with minimal side effects when compared to parental *Salmonella* vaccines (Tagliabue, 1989).

Several virulence-attenuated *Salmonella* strains 5 (Black et al., 1987; Curtiss et al., 1989; Dougan et al., 1986; Dougan et al., 1987; Dougan et al., 1987) may also be useful as host cells in the practice of the present invention. A successful parenteral typhoid vaccine using a virulence-attenuated *S. typhi* (TAB) has been developed 10 (Kumar et al. 1974). Since *Salmonella* strains readily colonize the gut mucosal surface (Carter and Collins, 1974), interact with Peyer's patches (PP) (McGhee and Metecky, 1989), and persist in GALT prior to reaching systemic tissues, *Salmonella* strains are being 15 extensively investigated as oral vaccine strains.

Transformed cells may be selected using various 20 techniques including screening by differential hybridization, identification of fused reporter gene products, resistance markers, anti-antigen antibodies, and the like. After identification of an appropriate clone, cells may be selected and cultivated under conditions appropriate to the circumstances, as for example, conditions favoring expression.

25

Another aspect of the invention is a method of preparing heterologous polypeptides. The method generally involves preparing one or more of the 30 recombinant vectors herein disclosed, transforming a host cell with the recombinant vector, then selecting a vector containing host cell clone and finally isolating from the clone the desired polypeptide which will be a heterologous protein. Examples of useful proteins that might be used in preparing the recombinant vector include 35 APase, cholera toxin B subunit, influenza hemagglutinin and neuraminidase epitopes, fragments of these proteins, or other desired proteins such as *E. coli* heat labile or

heat stable toxins, tetanus and pertussis toxins, botulinum and *Pseudomonas* exotoxin A, *Yersinia pestis* pestin and Vw antigen, listerolysis O, *Mycobacterium tuberculosis* membrane proteins or membrane proteins from 5 any pathogenic or related bacterium, also proteins which mediate attachment to mucosal surfaces such as but not limited to *E. coli* type 1 fimbriae, or mediate bacterial uptake into eucaryotic cells such as but not limited to the *Shigella flexneri ipaBCD* proteins, protective 10 antigens of pathogenic bacteria which are established or will become known.

Unlike gene fusions which are incorporated into the flagellin gene, or expressed fused to *lamB* described in 15 the prior art, much larger pieces of heterologous gene sequences can be displayed on the *Salmonella* surface with the present invention. Flagellin gene fusions are restricted to small epitopes which will not interfere with flagellar export and assembly at the cell surface. 20

In contrast, relatively large segments of heterologous fusion proteins representing a large number of epitopes can be exported and displayed by this invention. The *bla* gene described in the prior art may 25 have a similar capacity to export large heterologous fusion proteins, but the size limit has not been determined.

A clear advantage of the present invention is that 30 in *Salmonella*, the expression of fusion proteins will be under normal *Salmonella* regulation. This will abrogate problems with overproduction lethality which is often observed in the inferior systems described in the prior art. This is of extreme importance with the expression 35 of membrane proteins, and is a feature of the present invention which is clearly lacking in systems such as *bla* or *lamB* fusion systems.

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Depending on the particular recombinant vector selected for transforming a host cell, recombinant heterologous polypeptides will be expressed in different areas of the cell. For those heterologous polypeptides 5 expressed on the periplasmic face of the cytoplasmic membrane, or within the periplasmic space itself, isolation of the heterologous polypeptide may be achieved by cell lysis and other well-known procedures utilized in the isolation of a desired fusion protein. Heterologous 10 fusion proteins exported to or through the outer membrane of the host cell may be isolated from the membranes themselves. Typical procedures include separation of inner and outer cell membranes by procedures such as sonication, disruption by high pressure (French press), 15 disruption by chaotropic agents or detergents, followed by enzymatic treatment to remove RNA and/or DNA. After cellular disruption, membrane fragments can be isolated by ultracentrifugation to pellet the membrane fraction or alternatively membranes can be isolated on sucrose 20 density gradients. Inner and outer membranes can be isolated by selective solubilization of the inner membrane by detergents or via sucrose density gradient centrifugation. Ready isolation of the fusion peptide from membranous material, is also easily achieved by 25 methods well-known to those of skill in the art.

In certain embodiments, antigenic proteins are expressed on or close to the outer surface of the host cell. This allows a wide range of uses, ranging from 30 vaccine preparation to assays for screening of epitopes particularly effective for stimulating an immune response. Selected epitopes of eukaryotic, viral, or prokaryotic pathogens expressed on the surface of a host cell may be used for vaccine development. It is 35 contemplated that tumor specific genes may also be expressed and utilized to stimulate an immune response. Whole cells expressing immunogenic epitopes might be used

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for agglutination-based screening tests. Surface expressed polypeptides of microorganisms would be readily identified by screening recombinant libraries for specific surface expressed polypeptides.

5

In one particular aspect of the invention, cholera toxin B subunit is expressed on the surface of a *Salmonella* transformed host cell using the new pZIP-OUT vector. When expressed from *Salmonella* strain TA2362 harboring pRSP-18 (FIG. 2), cholera toxin B subunits reacts to antisera, and exhibits agglutination, indicating exposure of epitopic regions on the external membrane surface of the whole cell.

15

Yet another aspect of the invention involves the preparation of vaccines. Antigens or epitopes of the desired antigen are selected and a gene encoding that antigen or epitopes of that antigen is inserted into one or more of the recombinant vectors disclosed.

20

Appropriate host cells are transformed and after screening for transformants one is selected expressing the antigen or part of the antigen for which a vaccine is desired.

25

Vaccines may be prepared by any of a number of ways. For example, surface expressed antigens on host cells of the present invention may be safely ingested and are suitable for oral administration. Orally administered attenuated *Salmonella* cells, as discussed, are known to engender a good immunogenic response due to stimulation 30 of a reaction through interaction with gut mucosa.

35

Likewise, cell fragments or subcellular fractions containing the membrane-bound antigen prepared in accordance with the present invention, may be safely ingested and are also suitable for oral administration. This would be particularly desirable in the case of

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immunocompromised or immunosuppressed subjects wherein administration of the attenuated *Salmonella* cells themselves are unsuitable for oral administration.

5        Alternatively, cells, cell fragments, or subcellular fractions containing the membrane-localized antigen may be injected into a mammal to generate an immune response.

10      In both immunodiagnostics and vaccine preparation, it is often possible and indeed more practical to prepare antigens from segments of a known immunogenic protein or polypeptide. Certain epitopic regions may be used to produce responses similar to those produced by the entire antigenic polypeptide. Often responses to epitopic regions are not so strong as responses to the entire polypeptide. The epitopic regions if expressed on the outer membrane surface of a bacterial host cell are expected to generate immunogenic responses that are enhanced over responses of the free epitopic region.

20      Antigenic peptides expressed on bacterial host cell surfaces may be significant in developing vaccines to such important antigens as cholera toxin B subunit, influenza HA and N (neuraminidase), various HIV antigens, as well as but not limited to antigens which could offer protection to established infectious agents such as *Borrelia* sp. (the agent of Lyme disease), *Mycobacterium tuberculosis*, *M. leprae*, other mycobacteria such as those associated with immunosuppressed states (e.g., *M. avium* and *M. intracellulare*), *Mycoplasma pneumoniae* and other pathogenic mycoplasmas, *Neisseria gonorrhoeae* and *N. meningitidis*, *Pseudomonas aeruginosa* and other pathogenic or opportunistic pseudomonads, *Legionella pneumophila*, pathogenic obligate intracellular bacteria (e.g., *Rickettsia* sp., *Chlamydia* sp., *Ehrlichia* sp. *Coxiella* sp., also pathogenic *Yersinia* sp. (e.g., *Y. pestis*, *Y. pseudotuberculosis*, *Y. enterocolitica* and related

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species), *Pasteurella* sp., *Francisella* sp., *Bordetella* sp., *Nocardia* sp., *Campylobacter jejuni* and related species, *Helicobacter pylori*, *Treponema pallidum* and other treponemas, *Leptospira* sp., *Listeria monocytogenes*, 5 *Actinomyces* and related species, *Haemophilus influenzae* and related species, *Brucella abortus*, pathogenic *Shigella* species, pathogenic Gram-positive species (e.g., *Staphylococcus aureus*, *Streptococcus pyogenes*, as well as Group B, Group G and related forms, *Acinetobacter* sp., 10 *Corynebacterium diphtheriae*, anaerobic bacteria such as *Bacteroides fragilis*, pathogenic *Clostridium* sp., including *C. difficile*, *C. perfringens* and others, pathogenic anaerobic cocci (e.g., *Peptostreptococcus* and *Veillonella* sp.) and pathogenic *E. coli* species. It is 15 anticipated that these methods could be used for both but not limited to human and animal pathogens.

It is also contemplated that these methods could be used to develop vaccines to various pathogenic viruses. 20 These include but are not limited to Alphaviruses (Togaviride), Flaviviruses, Picornaviruses, Bunyaviruses, Arenaviruses, Orthomyxoviruses, Paramyxoviruses, Coronaviruses, Rhabdoviruses, retroviruses, rotaviruses, reoviruses, orbiviruses, parvoviruses, Norwalk agent, 25 papovaviruses, adenoviruses, herpes viruses, poxviruses, and hepatitis viruses.

These methods could also be used to produce novel vaccines against fungal and parasitic pathogens such as: 30 agents which mediate deep mycoses, subcutaneous, cutaneous, and superficial mycoses. Also, these methods could produce vaccines to protozoa such as *Dientamoeba*, *Trichomonas vaginalis* and others, hemoflagellates, malarial species, *Toxoplasma gondii*, *Pneumocystis carinii*, helminths, schistosomes, trematodes, cestodes 35 and nematodes including filarial nematodes.

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It is also anticipated that the methods of the present invention will be useful for vaccine development to emerging infectious agents such as Ebola virus, Hanta virus and others (Baron, 1991).

5

In other embodiments, the invention concerns primers capable of priming amplification of selected portions of disclosed DNA segments. As such, it is contemplated that oligonucleotide fragments corresponding to the sequences 10 of SEQ ID NO:1 and SEQ ID NO:2 for stretches of between about 10 nucleotides to about 20 or to about 30 nucleotides will find particular utility, with even longer sequences, e.g., 40, 50, 100, even up to full length, being more preferred for certain embodiments.

15 The ability of such nucleic acid probes to specifically hybridize to *Salmonella* sequences will enable them to be of use in a variety of embodiments. For example, the probes can be used in a variety of assays for detecting the presence of complementary sequences in a given 20 sample. However, other uses are envisioned, including the use of the sequence information for the preparation of mutant species primers, or primers for use in preparing other genetic constructions.

25 Nucleic acid molecules having stretches of 10, 20, 30, 50, or even of 100 nucleotides or so, complementary to SEQ ID NO:1 and SEQ ID NO:2 will have utility as hybridization probes. These probes will be useful in a variety of hybridization embodiments, such as Southern 30 and Northern blotting in connection with analyzing surface- and periplasmic-directed fusion proteins and/or polypeptides including those having either structural or regulatory function in diverse organisms and in various strains and/or species. The total size of fragment, as 35 well as the size of the complementary stretch(es), will ultimately depend on the intended use or application of the particular nucleic acid segment. Smaller fragments

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will generally find use in hybridization embodiments, wherein the length of the complementary region may be varied, such as between about 14 and about 100 nucleotides, or even up to full length according to the 5 complementary sequences one wishes to detect.

The use of a hybridization probe of about 14 nucleotides in length allows the formation of a duplex molecule that is both stable and selective. Molecules 10 having complementary sequences over stretches greater than 14 bases in length are generally preferred, though, in order to increase stability and selectivity of the hybrid, and thereby improve the quality and degree of specific hybrid molecules obtained. One will generally 15 prefer to design nucleic acid molecules having gene-complementary stretches from about 15 to 20 or 30 nucleotides, or even longer where desired. Such fragments may be readily prepared by, for example, directly synthesizing the fragment by chemical means, by 20 application of nucleic acid reproduction technology, such as the PCR™ technology of U.S. Patent 4,683,202 (herein incorporated by reference) or by introducing selected sequences into recombinant vectors for recombinant production.

25

Of course, for some applications, for example, where one desires to prepare mutants employing a mutant primer strand hybridized to an underlying template or where one seeks to isolate surface-directed polypeptide or protein-30 encoding sequences from related species, functional equivalents, or the like, less stringent hybridization conditions will typically be needed in order to allow formation of the heteroduplex. In these circumstances, one may desire to employ conditions such as about 0.15 M 35 to about 0.9 M salt, at temperatures ranging from about 20°C to about 55°C. Cross-hybridizing species can thereby be readily identified as positively hybridizing

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signals with respect to control hybridizations. In any case, it is generally appreciated that conditions can be rendered more stringent by the addition of increasing amounts of formamide, which serves to destabilize the 5 hybrid duplex in the same manner as increased temperature. Thus, hybridization conditions can be readily manipulated, and thus will generally be a method of choice depending on the desired results.

10 In certain embodiments, it will be advantageous to employ nucleic acid sequences of the present invention in combination with an appropriate means, such as a label, for determining hybridization. A wide variety of appropriate indicator means are known in the art, 15 including fluorescent, radioactive, enzymatic or other ligands, such as avidin/biotin, which are capable of giving a detectable signal. In preferred embodiments, one may desire to employ a fluorescent label or an enzyme tag, such as urease, alkaline phosphatase or peroxidase, 20 instead of radioactive or other environmental undesirable reagents. In the case of enzyme tags, colorimetric indicator substrates are known which can be employed to provide a means visible to the human eye or spectrophotometrically, to identify specific 25 hybridization with complementary nucleic acid-containing samples.

In general, it is envisioned that the hybridization probes described herein will be useful both as reagents 30 in solution hybridization as well as in embodiments employing a solid phase. In embodiments involving a solid phase, the test DNA (or RNA) is adsorbed or otherwise affixed to a selected matrix or surface. This fixed, single-stranded nucleic acid is then subjected to 35 specific hybridization with selected probes under desired conditions. The selected conditions will depend on the particular circumstances based on the particular criteria

required (depending, for example, on the G+C content, type of target nucleic acid, source of nucleic acid, size of hybridization probe, etc.). Following washing of the hybridized surface so as to remove nonspecifically bound 5 probe molecules, specific hybridization is detected, and quantitated if desired, by means of the label.

The nucleic acid segments of the present invention, regardless of the length of the coding sequence itself, 10 may be combined with other DNA sequences, such as promoters, polyadenylation signals, additional restriction enzyme sites, multiple cloning sites, other coding segments, and the like, such that their overall length may vary considerably. It is contemplated that a 15 nucleic acid fragment of almost any length may be employed, with the total length preferably being limited by the ease of preparation and use in the intended recombinant DNA protocol.

20 It will be understood that this invention is not limited to the particular nucleic acid and amino acid sequences of SEQ ID NO:1 and SEQ ID NO:2. Therefore, DNA segments prepared in accordance with the present invention may also encode biologically functional 25 equivalent proteins or peptides which have variant amino acids sequences. Such sequences may arise as a consequence of codon redundancy and functional equivalency which are known to occur naturally within nucleic acid sequences and the proteins thus encoded. 30 Alternatively, functionally equivalent proteins or peptides may be created via the application of recombinant DNA technology, in which changes in the protein structure may be engineered, based on considerations of the properties of the amino acids being 35 exchanged.

Primers may be utilized for several purposes. For example, primers may be used to amplify selected portions of the disclosed DNA segments. Certain combinations of the amplified segments may prove more effective than 5 others in efficiently targeting to inner or outer periplasmic membranes. Additionally, primers prepared from the disclosed DNA may be used to amplify regions of DNA from other related organisms in order to identify similar targeting sequences.

10

Once amplified products are obtained, they may be used as probes to detect and isolate selected DNA fragments using hybridization procedures. Like primers, probes may be DNA or RNA and are generally of similar 15 size usually including at least a 10 nucleotide segment or more, often 15-25 base pairs. Probes may be labeled, for example, by radiolabeling, to assist in identification of nucleic acid sequences.

20

As part of the invention, kits useful for the expression of fusion proteins are also envisioned comprising separate containers, each having suitably aliquoted reagents for performing the foregoing methods. For example, the containers may include one or more 25 *Salmonella* species or *E. coli* transformed to express an immunogenic protein either periplasmically or associated with the inner periplasmic membrane or associated with the outer membrane of the selected microorganism, either as whole cell preparations or as membrane fragments that 30 include the desired immunogen. Particularly valuable embodiments will be those that provide immunogenic response to epidemic diseases such as cholera, influenza, human immunodeficiency virus and so forth. A particularly preferred embodiment is attenuated 35 *Salmonella* harboring cholera toxin B subunit. Also included is a pharmaceutical vehicle for mixing with the cell or membrane fragments, preferably a liquid that is

suitable for oral administration.: Such liquids have been previously discussed herein.

Suitable containers might be vials made of plastic  
5 or glass, various tubes such as test tubes, metal cylinders, ceramic cups or the like. Containers may be prepared with a wide range of suitable aliquots, depending on applications and on the scale of the preparation. Generally this will be an amount that is  
10 conveniently handled so as to minimize handling and subsequent volumetric manipulations. Most practitioners will prefer to select suitable endonucleases from common supplies usually on hand; however, such restriction endonucleases may also be optionally included in a kit  
15 preparation.

Vectors, whole cells, membrane preparations, or membrane fragments containing the immunogenic fusion proteins supplied in kit form are preferably supplied in  
20 lyophilized form, although such cells, membrane preparations or membrane fragments may also be taken up in a suitable pharmaceutically-acceptable vehicle such as aqueous ethanol solutions, glycols, syrups, elixirs, or the like and supplied as solutions, suspensions, or  
25 colloids.

The kits of the invention may comprise distinct container means for each component, or multiple container means. The kits of the present invention may also  
30 include a means for containing the individual containers in close confinement for commercial sale, such as, e.g., injection or blow-molded plastic containers into which the desired vials or container means are retained.

BRIEF DESCRIPTION OF THE DRAWINGS

5        **FIG. 1.** Immunoblot analysis of outer membrane preparations of *Salmonella* harboring pAH13. Immunoblot probed with an anti-gp120 polyclonal antibody showing a *Salmonella*::*PhoA*::gp120/gp41 fusion protein. Lane A contains *E. coli* DH5 $\alpha$ <sup>TM</sup> control; lane B, *E. coli* DH5 $\alpha$ <sup>TM</sup> harboring pAH13; lane C, *S. typhimurium* TA2362; lane D, TA2362 harboring pAH13; lane E CEM cells infected with 10 HIV213; and lane F, CEM cells. The location of the predicted 84-kDa fusion protein is indicated in lanes B and D (\*). The HIV gp120 polypeptide is shown in HIV-infected CEM cells (#).

15        **FIG. 2.** Schematic for the construction of the *ctxB* fusion vector pRSP-18. pRSP-18 was constructed by first eliminating the *SspI* site between *EcoRI* and *PstI* of pRIT10810. In the second step a *HindIII/PvuII* fragment containing *Salmonella* expression and export signals 20 (*Sal'*) of the *phoA* fusion from pZIP-OUT was purified and ligated to a *HindIII/SspI* digest of pRIT10810. pSP18 containing 'ctxB' fused in frame with 'phoA' resulted from blunt ended ligation of the *PvuII* and *SspI* sites. Since pSP18 conferred only low level resistance to tetracycline 25 a cassette containing the kanamycin resistance gene was introduced at the *BamHI* site resulting in pRSP-18. The tribrid *ctxB* fusion is under control of the *Salmonella* expression and export signals of pZIP-OUT.

30        **FIG. 3.** Schematic for the construction of the *ctxB* fusion vector pIMB13. pIMB13 was constructed by first eliminating the *SspI* site in the vector portion of pZIP-IN by deleting an *EcoRV/SspI* fragment. In the second step an *SspI* fragment containing 'ctxB' from pRIT10810 was 35 introduced at the *SspI* site of pZIP-IN. Blunt-ended ligation resulted in pIMB13, which contains a fusion of

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'ctxB' in frame with the 'phoA' gene and *Salmonella* expression and export signals (*SalI'*) of pZIP-IN.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

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The present invention relates to nucleic acid segments encoding particular proteins, peptides, or polypeptides capable of forming fusion proteins that export to particular areas of a host cell. These nucleic acid segments are useful in constructing vectors that allow expression of heterologous proteins from appropriately transformed host cells. Polypeptides may be localized within the inner membrane/periplasmic space or exported to the cell membrane surface. Antigens or epitopic regions of antigens localized on host cell membranes have particular potential for vaccine development and antibody production.

Construction of an Export-Directing Vector

20

A novel plasmid vector, pZIP-OUT, has been developed that through the production of fusion polypeptides directs the products of heterologous genes to the surface of the *Salmonella* outer membrane (OM). An important element of this plasmid is a sequence that provides the proper motif for the export of polypeptides to the surface of the OM. pZIP-OUT2 is a derivative of this plasmid which has a single *Pvu*II site within the *phoA* gene.

30

To document that the plasmid-encoded *Salmonella* export sequences directs a fusion protein to the OM, subcellular fractions of *Salmonella* harboring pZIP-OUT were prepared to yield total envelope (TE), OM and inner membrane (IM) preparations (Curtiss et al., 1986). These were analyzed by immunoblotting by probing with a monoclonal antibody (MoAb) to APase (CalTag Inc., South

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San Francisco, CA). An APase fusion protein was observed in pZIP-OUT-containing cells that was present at high levels in the OM and TE, while only trace amounts were present in the IM.

5

In related studies, whole cell extractions enriched for surface proteins were prepared and surface-exposed polypeptides were extracted from *Salmonella* harboring pZIP-OUT by mild urea extraction (Foulaki and Gruber, 10 1989). Ten ml of overnight stationary phase bacterial cultures grown in LB broth were cooled on ice for 10 minutes and pelleted at 7,000  $\times$  g. The bacterial pellet was washed 3X in phosphate buffered saline (PBS). The washed pellet was resuspended in 0.1 ml of 6 M urea 15 containing 10 mM Tris-HCl, pH 7.5 and 5mM EDTA. The suspension was incubated on ice for 20 min. Bacteria were pelleted at 12,000  $\times$  g in a microcentrifuge. Supernatants were removed and frozen at -20°C for analysis of surface proteins.

20

Immunoblot analysis of these surface extracts probed with a MoAb to APase showed pZIP-OUT mediated surface expression of an APase fusion protein, indicating that the APase fusion protein is directed to the OM surface.

25

#### DNA Sequence Determination

DNA sequence across the *phoA* fusion joint upstream into *Salmonella* sequence was determined for pZIP-OUT. A 30 promoter (underlined) and Shine-Dalgarno sequence (boxed) were identified. The derived amino acid sequence contains an export specifying lipoprotein cleavage sequence (Leu-Ile-Gly-Cys), which is similar with other prokaryotic 35 lipoprotein signal sequences (Wu and Tokunaga, 1985). A DNA sequence having homology to the described *Salmonella* sequence has recently been identified (Altmeyer, et al., 1993) and designated *invH*.

**The Utility of pZIP-OUT in Directing Membrane Expression of Target Gene Sequences**

The pZIP-OUT export-directing sequence is also 5 useful in facilitating membrane expression of a variety of target genes. In these studies, restriction sites within the *phoA* gene were utilized which allow maintenance of the correct reading frame to produce *Salmonella:PHOA:X* tribrid fusion proteins.

10

Using this approach, the *V. cholera* *ctxB* gene encoding the cholera toxin B subunit (CTB), was introduced into the *phoA* gene of pZIP-OUT (pRSP-18). A 32 kDa CTB fusion protein was observed in OM but not IM fractions of TA2362 harboring pRSP-18. Surface extracts from pRSP-18 harboring cells showed a 32 kDa-reactive band. Antisera to CTB agglutinated *Salmonella* harboring pRSP-18, but not this strain alone, indicated that epitopic region(s) of CTB expressed by pRSP-18 was 15 exposed on the surface of the cell.

**Production of CTB-antibodies in Strains Harboring pRSP-18 Constructs**

25 Cultures of attenuated *Salmonella* bacteria are prepared for oral immunization using about  $2 \times 10^8$  to  $2 \times 10^9$  CFU in phosphate buffered saline (PBS) containing 3% NaHCO<sub>3</sub>. Doses in this range have given optimal responses in the present studies, but may be adjusted 30 based on the particular subject and delivery vehicles used. Oral feeding of CTB (10-500  $\mu$ g) in PBS containing 3% NaHCO<sub>3</sub> is used as a control. Initial boosting occurs at 18-21 days postchallenge, with subsequent boosting as necessary. Mucosal and serum antibodies to CTB are 35 determined after primary challenge and all subsequent immunizations. CTB-specific Ig is quantitated using established ELISA protocols (Lycke et al., 1988) with CTB

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or CT bound to GM1 ganglioside-coated plates. Antibody levels to the *Salmonella* carrier strain are also determined. Titers to *Salmonella* are determined by a whole cell ELISA using *Salmonella* glutaraldehyde-fixed to 5 microtiter wells. Mucosal Ig responses are determined from extracts of intestinal scrapings (Van der Heijden et al., 1991) by ELISA. Horseradish peroxidase-(HRP) or AP-conjugated monoclonal antibodies are used for detection. Commercially available conjugated Ig-specific 10 monoclonal antibodies to IgG, IgM and IgA facilitate determination of the isotype of the CTB-specific antibodies.

#### Development of pZIP-OUT

15

A heterologous gene expression system has been developed which utilizes a virulence-attenuated *Salmonella* as a carrier for a plasmid expression system (pZIP-OUT) which can direct the products of large 20 segments of heterologous genes to the outer membrane. Recombinant DNA techniques are utilized to fuse the reading frame of the gene to be expressed with *Salmonella* export specifying sequences. Several cloning sites are possible which allow maintenance of the proper reading 25 frame and produce tribrid fusion polypeptides which contain *Salmonella* export specifying sequences, the heterologous gene sequences and *phoA* gene sequences. Recombinants which export the tribrid fusion protein are selected through the loss of *phoA* activity and appearance 30 of the predicted fusion polypeptide on the surface of the outer membrane. A tribrid fusion was constructed that encodes virtually the entire cholera toxin B subunit (*ctxB*) gene, and its subcellular localization in *Salmonella* was determined. This fusion polypeptide is 35 expressed on the *Salmonella* surface as evidenced by: 1) agglutination of tribrid fusion expressing strains by anti-CTB antiserum, 2) localization of the fusion

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polypeptide in the outer membrane; and 3) the presence of the fusion polypeptide in cell surface preparations.

DNA encoding the exported polypeptide of the present invention was isolated from *S. typhimurium*, strain TA2362, a virulence-attenuated strain. Virulence attenuated refers to species that have lost one or more virulence factors. In some *Salmonella* strains the loss of large plasmids is associated with loss of virulence, while in other strains chromosomal determinants of virulence appear to be involved. Isolation of an attenuated strain of *Salmonella* was useful in developing the present invention because such strains may be used to deliver heterologous antigens to the gut of an animal. *Salmonella* given orally tends to establish an infection in the intestinal mucosa, leading to an immune response.

The approach to screening for protein export signals was to use APase fusions based on the *TnphoA* transposon system reviewed by Manoil et al. (1990). *TnphoA* is a transposon derivative of *Tn5* which lacks promoter, translation initiation site, signal sequence DNA and the first five amino acids of its protein. When the transposon, *TnphoA*, inserts into a foreign gene in the correct orientation and reading frame, gene fusions are generated, coding for hybrid proteins which are subsequently expressed having APase activity. Detection of such activity is generally accomplished with a phosphatase-specific chromogenic substrate, such as 5-bromo-4-chloro-3-indolyl phosphate (X-P), allowing visualization of colored colonies for successful gene fusions that lead to export of heterologous gene products.

**Vaccine Preparation and Use**

Vaccines are the most cost effective medical intervention known to prevent disease. However, 5 effective vaccines are available for relatively few diseases. Successful immunization against infectious organisms often requires a multicomponent host immune response against a variety of antigenic determinants. Orally administered vaccines, especially live attenuated 10 vaccines, induce specific cell-mediated effector responses and elicit secretory IgA (sIgA) responses. sIgA is important because of its effectiveness at mucosal surfaces. sIgA production and cell effector responses are mediated through the delivery of antigens to gut-associated lymphoid tissue (GALT). Stimulation of GALT 15 can lead to effective cell and humoral defense at all mucosal surfaces and provide systemic protection (Majarian et al., 1989; Metecky, 1987).

20 To deliver antigens to GALT, investigators have developed avirulent and virulence-attenuated *Salmonella* stains. Aromatic dependent *aroA* (Sadoff et al., 1988), *phoN* (Poirier et al., 1988), *gale* (Clements, 1989), and *cya/crp* (Brown et al., 1987) *Salmonella* mutants have been 25 reported to interact with GALT in the lamina propria and stimulate an immune response. While it is clearly desirable to use avirulent *Salmonella* strains as carriers for plasmids which express protective antigens of other pathogens on their surface, there has been little success 30 in developing protective vaccines based on this system.

The present invention includes vaccine preparation and use. Antigens, or epitopes of antigens, are readily expressed in localized regions of a host cell using the 35 methods disclosed. Expression vectors incorporating the DNA segment encoding exportation polypeptides direct products to a host cell outer membrane surface. Epitopic

regions of antigens, well exposed at a membrane surface, as demonstrated with cholera toxin subunit B, elicit immunogenic responses, providing a route to vaccines or antibody production.

5

General concepts related to methods of vaccine preparation and use are discussed as applicable to preparations and formulations with antigens, epitopes or sub-fragments of such antigens obtained from various 10 sources. Although virtually any antigen is contemplated, specific examples of antigens may include cholera toxin B subunit, influenza hemagglutinin, influenza neuraminidase, rickettsial outer membrane (OM) p190 protein, bacterial endotoxins, exotoxins, and the like.

15

Preparation of vaccines which contain peptide sequences as active ingredients is generally well understood in the art, as exemplified by U.S. Patents 4,608,251; 4,601,903; 4,599,231; 4,599,230; 4,596,792; 20 and 4,578,770, all incorporated herein by reference. Typically, such vaccines are prepared as injectables either as liquid solutions or suspensions; solid forms suitable for solution in, or suspension in, liquid prior to injection may also be prepared. The preparation may 25 also be emulsified. The active immunogenic ingredient is often mixed with excipients which are pharmaceutically acceptable and compatible with the active ingredient. Suitable excipients are, for example, water, saline, dextrose, glycerol, ethanol, or the like, and 30 combinations thereof. In addition, if desired, the vaccine may contain minor amounts of auxiliary substances such as wetting or emulsifying agents, pH buffering agents, or adjuvants which enhance the effectiveness of the vaccines.

35

Vaccines are preferably administered orally, although parenterally, by injection, or either

subcutaneously or intramuscularly, is also contemplated. Additional formulations which are suitable for other modes of administration include suppositories and oral formulations. For suppositories, traditional binders and 5 carriers may include, for example, polyalkylene glycols or triglycerides; such suppositories may be formed from mixtures containing the active ingredient in the range of 0.5% to 10%, preferably 1-2%. Oral formulations include such normally employed excipients as, for example, 10 pharmaceutical grades of mannitol, lactose, starch, magnesium stearate, sodium saccharine, cellulose, magnesium carbonate, and the like. These compositions take the form of solutions, suspensions, tablets, pills, capsules, sustained release formulations or powders and 15 contain 10-95% of active ingredient, preferably 25-70%.

Proteins may be formulated into the vaccine as neutral or salt forms. Pharmaceutically acceptable salts include acid addition salts (formed with the free amino 20 groups of the peptide) and which are formed with inorganic acids such as, for example, hydrochloric or phosphoric acids, or such organic acids as acetic, oxalic, tartaric, mandelic, and the like. Salts formed with the free carboxyl groups may also be derived from inorganic 25 bases such as, for example, sodium, potassium, ammonium, calcium, or ferric hydroxides, and such organic bases as isopropylamine, trimethylamine, 2-ethylamino ethanol, histidine, procaine, and the like.

30 The vaccines are administered in a manner compatible with the dosage formulation, and in such amount as will be therapeutically effective and immunogenic. The quantity to be administered depends on the subject to be treated, including, e.g., the capacity of the 35 individual's immune system to synthesize antibodies, and the degree of protection desired. Precise amounts of active ingredient required to be administered depend on

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the judgment of the practitioner. However, suitable dosage ranges are of the order of several hundred micrograms active ingredient per vaccination. Suitable regimes for initial administration and booster shots are 5 also variable but are typified by an initial administration followed by subsequent inoculations or other administrations. One will select particular avirulent strains depending upon the individual requirements of the subject receiving the vaccine.

10

Likewise, the manner of application may be varied widely. Any of the conventional methods for administration of a vaccine are applicable, particularly oral application on a solid physiologically acceptable 15 base or in a physiologically acceptable dispersion. Alternatively, administration may be parenterally, by injection or the like. The dosage of the vaccine will depend on the route of administration and will vary according to the size of the host.

20

Various methods of achieving adjuvant effect for the vaccine include use of agents such as aluminum hydroxide or phosphate (alum), commonly used as 0.05 to 0.1 percent solution in phosphate buffered saline, admixture with 25 synthetic polymers of sugars (Carbopol™) used as 0.25 percent solution, aggregation of the protein in the vaccine by heat treatment with temperatures ranging between 70° to 101°C for 30 second to 2 minute periods respectively. Aggregation by reactivating with pepsin 30 treated (Fab) antibodies to albumin, mixture with bacterial cells such as *C. parvum* or endotoxins or lipopolysaccharide components of gram-negative bacteria, emulsion in physiologically acceptable oil vehicles such as mannide mono-oleate (Aracel A™) or emulsion with a 20 35 percent solution of a perfluorocarbon (Fluosol-DA™) used as a block substitute may also be employed.

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In many instances, it will be desirable to have multiple administrations of the vaccine, usually not exceeding six vaccinations, more usually not exceeding four vaccinations and preferably one or more, usually at 5 least about three vaccinations. The vaccinations will normally be administered from two to twelve week intervals, more usually from three to five week intervals. Periodic boosters at intervals of 1-5 years, usually three years, will be desirable to maintain 10 protective levels of the antibodies. The course of the immunization may be followed by assays for antibodies for the supernatant antigens. The assays may be performed by labeling with conventional labels, such as radionuclides, enzymes, fluorescers, and the like. These techniques are 15 well known and may be found in a wide variety of patents, such as U.S. Patent Nos. 3,791,932; 4,174,384 and 3,949,064, as illustrative of these types of assays. Alternatively, the course of the immunization may be followed by intestinal lavage with quantitation of the 20 attenuated cells containing the surface-directed antigen.

#### Host Cells and Construction of Expression Vectors

The invention also contemplates the use of disclosed 25 nucleic acid segments in the construction of expression vectors or plasmids and use in host cells. The following is a general discussion relating to such use and the particular considerations in practicing this aspect of the invention.

30

In general, of course, prokaryotes, and in particular *Proteobacteria*, are preferred for the initial cloning of DNA sequences and constructing the vectors useful in the invention. Most preferred are members of 35 the family *Enterobacteraceae*. For example, in addition to the particular genera mentioned in the more specific disclosure below, one may mention by way of example,

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genera such as *Escherichia*, *Salmonella*, and *Shigella*. More preferably strains such as *E. coli* K12 strain 294 (ATCC No. 31446), *E. coli* B, and *E. coli* X 1776 (ATCC No. 31537) are employed.

5

Prokaryotes are also preferred for expression, and more particularly, *Proteobacteria*, including strains of such species as *E. coli* W3110 (F-, lambda-, prototrophic, ATCC No. 273325), or other *Enterobacteriaceae* such as 10 *Salmonella typhimurium* or *Serratia marcescens*, and various *Pseudomonas* species. Additional Gram-negative bacteria are also envisioned to be useful in the expression of the vectors of the present invention. Likewise, bacilli such as *Bacillus subtilis* are also 15 contemplated. These examples are, of course, intended to be illustrative rather than limiting.

In general, plasmid vectors containing replicon and control sequences which are derived from species 20 compatible with the host cell are used in connection with these hosts. The vector ordinarily carries a replication site, as well as marking sequences which are capable of providing phenotypic selection in transformed cells. For example, *E. coli* is typically transformed using pBR322, a 25 plasmid derived from an *E. coli* species (see, e.g., Bolivar et al., 1977). The pBR322 plasmid contains genes for ampicillin and tetracycline resistance and thus provides easy means for identifying transformed cells. The pBR322 plasmid, or other microbial plasmid or phage 30 must also contain, or be modified to contain, promoters which can be used by the microorganism for expression.

Those promoters most commonly used in recombinant DNA construction include the  $\beta$ -lactamase (penicillinase) 35 and lactose promoter systems (e.g.,  $\beta$ -galactosidase) (Chang et al., 1978; Itakura et al., 1977; Goeddel et al., 1979) and a tryptophan (*trp*) promoter system

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(Goeddel et al., 1979; EPO Appl. Publ. No. 0036776). While these are the most commonly used, other microbial promoters have been discovered and utilized, and details concerning their nucleotide sequences have been 5 published, enabling a skilled worker to ligate them functionally with plasmid vectors (Siebwenlist et al., 1980). Certain genes from prokaryotes may be expressed efficiently in *E. coli* from their own promoter sequences, precluding the need for addition of another promoter by 10 artificial means.

In addition to prokaryotes, eukaryotic microbes, such as yeast cultures may also be used. *Saccharomyces cerevisiae*, or common baker's yeast is the most commonly 15 used among eukaryotic microorganisms, although a number of other strains are available. For expression in *Saccharomyces*, the plasmid YRp7, for example, is commonly used (Stinchcomb et al., 1979; Kingsman et al., 1979; Tschemper et al., 1980). This plasmid already contains 20 the *trpL* gene which provides a selection marker for a mutant strain of yeast lacking the ability to grow in tryptophan, for example ATCC No. 44076 or PEP4-1 (Jones, 1977). The presence of the *trpL* lesion as a characteristic of the yeast host cell genome then 25 provides an effective environment for detecting transformation by growth in the absence of tryptophan.

Suitable promoting sequences in yeast vectors include the promoters for 3-phosphoglycerate kinase 30 (Hitzman et al., 1980) or other glycolytic enzymes (Hess et al., 1968; Holland et al., 1978), such as enolase, glyceraldehyde-3-phosphate dehydrogenase, hexokinase, pyruvate decarboxylase, phosphofructokinase, glucose-6-phosphate isomerase, 3-phosphoglycerate mutase, pyruvate 35 kinase, triosephosphate isomerase, phosphoglucose isomerase, and glucokinase. In constructing suitable expression plasmids, the termination sequences associated

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with these genes are also ligated into the expression vector 3' of the sequence desired to be expressed to provide polyadenylation of the mRNA and termination.

5 Other promoters, which have the additional advantage of transcription controlled by growth conditions are the promoter region for alcohol dehydrogenase 2, isocytochrome C, acid phosphatase, degradative enzymes associated with nitrogen metabolism, the aforementioned 10 glyceraldehyde-3-phosphate dehydrogenase, and enzymes responsible for maltose and galactose utilization. Any plasmid vector containing a yeast-compatible promoter, origin of replication and termination sequences is suitable.

15

In addition to prokaryotic organisms, cultures of eukaryotic cells derived from multicellular organisms may also be used as hosts in both the construction and expression of aspects of the present invention. In 20 principle, any such cell culture is useful, whether from vertebrate or invertebrate culture. However, interest has been greatest in vertebrate cells, and propagation of vertebrate cells in culture (tissue culture) has become a routine procedure in recent years (Tissue Culture, 1973). 25 Examples of such useful host cell lines are VERO and HeLa cells, Chinese hamster ovary (CHO) cell lines, and W138, BHK, COS-7 293 and MDCK cell lines. Expression vectors for such cells ordinarily include (if necessary) an origin of replication, a promoter located in front of the 30 gene to be expressed, along with any necessary ribosome binding sites, RNA splice sites, polyadenylation site, and transcriptional terminator sequences.

For use in mammalian cells, the control functions on 35 the expression vectors are often provided by viral material. For example, commonly used promoters are derived from polyoma, Adenovirus 2, and most frequently

Simian Virus 40 (SV40). The early and late promoters of SV40 virus are particularly useful because both are obtained easily from the virus as a fragment which also contains the SV40 viral origin of replication (Fiers et 5 al., 1978). Smaller or larger SV40 fragments may also be used, provided there is included the approximately 250 bp sequence extending from the *Hind*III site toward the *Bgl*II site located in the viral origin of replication. Further, it is also possible, and often desirable, to 10 utilize promoter or control sequences normally associated with the desired gene sequence, provided such control sequences are compatible with the host cell systems.

An origin of replication may be provided either by 15 construction of the vector to include an exogenous origin, such as may be derived from SV40 or other viral (e.g., Polyoma, Adeno, VSV, BPV) source, or may be provided by the host cell chromosomal replication mechanism. If the vector is integrated into the host 20 cell chromosome, the latter is often sufficient.

Also contemplated within the scope of the present invention is the use of the disclosed DNA as a hybridization probe. While particular examples are 25 provided to illustrate such use, the following provides general background for hybridization applications taking advantage of the disclosed nucleic acid sequences of the invention.

### 30 Nucleic Acid Hybridization Embodiments

In certain aspects, the DNA sequence information provided by the invention allows for the preparation of relatively short DNA (or RNA) sequences having the 35 ability to specifically hybridize to *S. typhimurium* gene sequences. In these aspects, nucleic acid probes of an appropriate length are prepared based on a consideration

of the sequence, e.g., as shown SEQ ID NO:1 and SEQ ID NO:2 or derived from flanking regions of these genes. The ability of such nucleic acid probes to specifically hybridize to the *S. typhimurium* gene sequences lend them 5 particular utility in a variety of embodiments. The probes can be used in a variety of diagnostic assays for detecting the presence of pathogenic organisms in a given sample. However, other uses are envisioned, including the use of the sequence information for the preparation 10 of mutant species primers, or primers for use in preparing other genetic constructs.

To provide certain of the advantages in accordance with the invention, the preferred nucleic acid sequence 15 employed for hybridizations or assays includes sequences that are complementary to at least a 10 to 40, or so, nucleotide stretch of the selected sequence, such as that shown in SEQ ID NO:1 or SEQ ID NO:2, respectively. A size of at least 10 nucleotides in length helps to ensure 20 that the fragment will be of sufficient length to form a duplex molecule that is both stable and selective. Molecules having complementary sequences over stretches greater than 10 bases in length are generally preferred, though, in order to increase stability and selectivity of 25 the hybrid, and thereby improve the quality and degree of specific hybrid molecules obtained. Thus, one will generally prefer to design nucleic acid molecules having gene-complementary stretches of 15 to 20 nucleotides, or even longer where desired. Such fragments may be readily 30 prepared by, for example, directly synthesizing the fragment by chemical means, by application of nucleic acid reproduction technology, such as the PCR™ technology of U.S. Patent 4,683,202, or by introducing selected sequences into recombinant vectors for recombinant 35 production.

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The present invention is envisioned as useful in the cloning of nucleic acids encoding certain exportation polypeptides. Identification of other exportation polypeptides in addition to the 50 kDa and 63 kDa 5 proteins should be possible using methods analogous to those disclosed herein. One method would be to produce a cDNA library using mRNA obtained from mutant *S. typhimurium* strains. Although the production of cDNA libraries from bacteria is not commonly done because of 10 the usual absence of poly-A tails on prokaryotic messages, a cDNA library may be constructed from *S. typhimurium* mRNA.

A method of preparing variants of the *S. typhimurium* 15 exportation polypeptides is site-directed mutagenesis. This technique is useful in the preparation of individual peptides, or biologically functional equivalent proteins or peptides, derived from the 50 kDa or 63 kDa protein sequence, through specific mutagenesis of the underlying 20 DNA. The technique further provides a ready ability to prepare and test sequence variants, for example, incorporating one or more of the foregoing considerations, by introducing one or more nucleotide sequence changes into the DNA. Site-specific mutagenesis 25 allows the production of mutants through the use of specific oligonucleotide sequences which encode the DNA sequence of the desired mutation, as well as a sufficient number of adjacent nucleotides, to provide a primer sequence of sufficient size and sequence complexity to 30 form a stable duplex on both sides of the deletion junction being traversed. Typically, a primer of about 17 to 25 nucleotides in length is preferred, with about 5 to 10 residues on both sides of the junction of the sequence being altered.

35

In general, the technique of site-specific mutagenesis is well known in the art as exemplified by

publications (Adelman et al., 1983). As will be appreciated, the technique typically employs a phage vector which exists in both a single stranded and double stranded form. Typical vectors useful in site-directed 5 mutagenesis include vectors such as the M13 phage (Messing et al., 1981). These phage are readily commercially available and their use is generally well known to those skilled in the art.

10 In general, site-directed mutagenesis in accordance herewith is performed by first obtaining a single-stranded vector which includes within its sequence a DNA sequence which encodes an export polypeptide. An oligonucleotide primer bearing the desired mutated 15 sequence is prepared, generally synthetically, for example by the method of Crea et al. (1978). This primer is then annealed with the single-stranded vector, and subjected to DNA polymerizing enzymes such as *E. coli* polymerase I Klenow fragment, in order to complete the 20 synthesis of the mutation-bearing strand. Thus, a heteroduplex is formed wherein one strand encodes the original non-mutated sequence and the second strand bears the desired mutation. This heteroduplex vector is then used to transform appropriate cells, such as *E. coli* 25 cells, and clones are selected which include recombinant vectors bearing the mutated sequence arrangement.

30 The preparation of sequence variants of the selected exportation polypeptide gene using site-directed mutagenesis is provided as a means of producing potentially useful exportation species and is not meant to be limiting as there are other ways in which sequence variants of the exportation polypeptide gene may be obtained. For example, recombinant vectors encoding the 35 desired 30K gene may be treated with mutagenic agents to obtain sequence variants (see, e.g., a method described

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by Eichenlaub, [1979] for the mutagenesis of plasmid DNA using hydroxylamine).

#### Epitopic Core Sequences

5

Further embodiments of the present invention are thus contemplated to include protein compositions, free from total bacterial cells, characterized as being associated with outer membranes or fragments thereof and 10 having immunogenic activity. Such proteins may either be isolated directly by cell fractionation and protein purification or may be produced by recombinant techniques following the molecular cloning of a DNA segment, as described herein.

15

The present invention is also directed to protein, peptide or polypeptide compositions, free from total bacterial cells, which comprise a purified protein, peptide or polypeptide which incorporates an epitope that 20 is immunologically cross-reactive with a surface-directed fusion protein described herein.

As used herein, the term "incorporating an epitope(s) that is immunologically cross-reactive with a 25 surface-directed fusion protein" is intended to refer to a peptide or protein antigen which includes a primary, secondary or tertiary structure similar to an epitope associated with the outer membrane or periplasmic space of *Salmonella* or *E. coli* of an export-directed fusion 30 protein as described herein. The level of similarity will generally be to such a degree that monoclonal or polyclonal antibodies directed against the fusion protein will bind to, react with, or otherwise recognize, the cross-reactive peptide or protein antigen. Various 35 immunoassay methods may be employed in conjunction with such antibodies, such as, for example, Western blotting,

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Additionally or alternatively, an epitopic core sequence is one that will elicit antibodies that are cross-reactive with antibodies directed against the surface-expressed fusion proteins of the present invention. It 5 will be understood that in the context of the present disclosure, the term "complementary" refers to amino acids or peptides that exhibit an attractive force towards each other. Thus, certain epitope core sequences of the present invention may be operationally defined in 10 terms of their ability to compete with or perhaps displace the binding of the desired protein antigen with the corresponding protein-directed antisera.

15 In general, the size of the polypeptide antigen is not believed to be particularly crucial, so long as it is at least large enough to carry the identified core sequence or sequences. The smallest useful core sequence anticipated by the present disclosure would generally be on the order of about 15 amino acids in length. Thus, 20 this size will generally correspond to the smallest peptide antigens prepared in accordance with the invention. However, the size of the antigen may be larger where desired, so long as it contains a basic epitopic core sequence.

25

Syntheses of epitopic sequences, or peptides which include an antigenic epitope within their sequence, are readily achieved using conventional synthetic techniques such as the solid phase method (e.g., through the use of 30 commercially available peptide synthesizer such as an Applied Biosystems Model 430A Peptide Synthesizer). Peptide antigens synthesized in this manner may then be aliquotted in predetermined amounts and stored in conventional manners, such as in aqueous solutions or, 35 even more preferably, in a powder or lyophilized state pending use.

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ELISA, RIA, and the like, all of which are known to those of skill in the art.

The identification of immunogenic epitopes, and/or 5 their functional equivalents, suitable for use in vaccines is a relatively straightforward matter. For example, one may employ the methods of Hopp, as taught in U.S. Patent 4,554,101, incorporated herein by reference, which teaches the identification and preparation of 10 epitopes from amino acid sequences on the basis of hydrophilicity. The methods described in several other papers, and software programs based thereon, can also be used to identify epitopic core sequences (e.g., Jameson and Wolf, 1988; Wolf et al., 1988; Hopp, U.S. Patent 15 Number 4,554,101; and Kyte and Doolittle, 1982). The amino acid sequence of these "epitopic core sequences" may then be readily incorporated into peptides, either through the application of peptide synthesis or recombinant technology.

20

Preferred peptides for use in accordance with the present invention will generally be on the order of 15 to 50 amino acids in length, and more preferably about 15 to about 30 amino acids in length. It is proposed that 25 shorter antigenic peptides which incorporate epitopes of the surface-expressed fusion proteins will provide advantages in certain circumstances, for example, in the preparation of vaccines or in immunologic detection assays. Exemplary advantages include the ease of 30 preparation and purification, the relatively low cost and improved reproducibility of production, and advantageous biodistribution.

An epitopic core sequence, as used herein, is a 35 relatively short stretch of amino acids that is "complementary" to, and therefore will bind, antigen binding sites on transferrin-binding protein antibodies.

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In general, due to the relative stability of peptides, they may be readily stored in aqueous solutions for fairly long periods of time if desired, e.g., up to six months or more, in virtually any aqueous solution 5 without appreciable degradation or loss of antigenic activity. However, where extended aqueous storage is contemplated it will generally be desirable to include agents including buffers such as Tris or phosphate buffers to maintain a pH of 7.0 to 7.5. Moreover, it may 10 be desirable to include agents which will inhibit microbial growth, such as sodium azide or Merthiolate. For extended storage in an aqueous state it will be desirable to store the solutions at 4°C, or more 15 preferably, frozen. Of course, where the peptide(s) are stored in a lyophilized or powdered state, they may be stored virtually indefinitely, e.g., in metered aliquots that may be rehydrated with a predetermined amount of water (preferably distilled) or buffer prior to use.

20

#### **Isolation of *Salmonella* DNA Segments**

Isolation of *Salmonella* DNA segments was accomplished by isolation of *phoA*/DNA fusions. *TnphoA* is a derivative of *Tn5* which encodes *E. coli* APase, minus 25 the signal sequence and expression signals, inserted into the left *IS50L* element. Random transposition of *TnphoA* results in an active insertion only when the *phoA* gene sequence is fused in-frame downstream of the promoter and export signals of a target gene A. Plasmids containing 30 *phoA* gene fusions can then be used as exposition vectors (B). The *SspI* and the *PvuII* restriction sites in *phoA* are blunt ended sites at which in-frame insertions (IF) of a gene of interest (GOI) can be inserted. The resulting tribrid gene fusions contain the expression and 35 export signals of the target gene fused in-frame with the *phoA* and GOI sequences.

The following examples are intended to illustrate the practice of the present invention and are not intended to be limiting. Although the invention is demonstrated with nucleic acid segments isolated from a 5 strain of *Salmonella*, similar functions may be obtained from nucleic acid segments from other *Salmonella* species and strains, other *Enterobacteraceae*, and even other bacteria and higher microorganisms. The nucleic acid sequences identified and the corresponding encoded 10 polypeptides are useful in developing methods of producing a wide variety of heterologous proteins as well as expression vectors for localizing polypeptides in selected areas of a host cell.

15 It should be appreciated by those of skill in the art that the techniques disclosed in the examples which follow represent techniques discovered by the inventors to function well in the practice of the invention, and thus can be considered to constitute preferred modes for 20 its practice. However, those skilled in the art should, in light of the present disclosure, appreciate that many changes can be made in the specific embodiments which are disclosed and still obtain a like or similar result without departing from the spirit and scope of the 25 invention.

EXAMPLE 1

The following example illustrates construction of 30 plasmid pZIP-IN, as disclosed in U.S. Patent 5,356,797, the entire text and figures of which are specifically incorporated herein by reference in their entirety. This plasmid is basically a chimeric gene including a *Salmonella* DNA segment fused with a segment of an APase 35 gene lacking signal and expression sequences. When expressed in a suitable host cell, the fusion product is

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localized to the inner membrane/periplasmic space of the host cell.

#### PREPARATION OF pZIP-IN FUSION VECTOR

5

pZIP-IN, is a derivative of pBR322 containing a *Bam*HI fragment encoding APase activity and kanamycin resistance inserted at the *Bam*HI site. The *Bam*HI fragment was cloned from a chromosomal DNA preparation of 10 the *TnphoA* insertion mutant TAG28 that was constructed by *TnphoA* mutagenesis (see above) of *S. typhimurium* TA2361 (*phoN* mutant derived from LT2).

15 Chromosomal DNA was prepared from 50 ml of overnight growth of TAG28 in L-broth with vigorous shaking at 37°C. The bacterial culture was precipitated and washed once in phosphate buffered saline (pH 7.0). The washed bacterial pellet was resuspended in 10 ml of ice cold ET buffer (10 mM EDTA, 10 mM Tris-HCl, pH 8.0). Lysozyme was added to 20 a concentration of 0.1 mg/ml and incubated for 15 minutes at 37°C. 1.2 ml of sarkosyl-pronase solution (10% sarkosyl, 5 mg/ml Pronase in ET buffer) was added and the solution was incubated for 1 hr at 37°C. The solution was then extracted 3 times with TE (10 mM Tris HCl, 1 mM 25 EDTA, pH 8.0) saturated phenol followed by 3 extractions with chloroform:isoamyl alcohol (24:1). The aqueous phase was transferred to a 50 ml beaker on ice and one-half volume of 7.5 M ammonium acetate was added. Three volumes of ice cold absolute ethanol was gently layered 30 on top of the solution. The chromosomal DNA was precipitated onto a glass rod by gently stirring the solution to mix the interface. The precipitated DNA was rinsed once in 70% ice cold ethanol and dissolved overnight in 2 ml of TE buffer at 4°C. The concentration 35 of DNA was quantitated by measuring the O.D. at 260 nm.

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2  $\mu$ g of TAG28 chromosomal DNA was digested with *Bam*HI at 37°C for 2 hrs. The solution was extracted once with TE saturated phenol, followed by 2 extractions with chloroform:isoamyl alcohol (24:1). The aqueous phase was 5 removed and the DNA precipitated by the addition of 1/10 volume 3 M sodium acetate (pH 5.2) and 2 volumes of ethanol followed by centrifugation in a microcentrifuge. 0.2  $\mu$ g of pBR322 DNA was digested with *Bam*HI and prepared for ligation as above. Ligation of the vector DNA 10 (pBR322) and TAG28 chromosomal DNA was performed by overnight incubation at 4°C in 20  $\mu$ l of 1X commercial (Promega) ligase buffer and 2 U of T4 DNA ligase.

pZIP-IN was isolated from the ligation reaction by 15 transformation of DH5 $\alpha$ ™ (GIBCO-BRL, Bethesda, MD) competent cells. 5  $\mu$ l of the ligation mixture was added to 50  $\mu$ l of DH5 $\alpha$  competent cells and incubated on ice for 30 minutes. Cells were heat shocked for 30 seconds by submerging in a 37°C water bath. Cells were cooled on 20 ice for 2 minutes and 0.950 ml of L-Broth was added to the tube. Cells were incubated for 1 hr at 37°C. Transformants with APase activity and kanamycin resistance were selected by plating 0.1 ml of the bacterial culture on the L-agar plates containing 50 25  $\mu$ g/ml kanamycin and 40  $\mu$ g/ml X-P, followed by overnight incubation at 37°C. The following day, kanamycin resistant colonies were visible and all were blue, indicating that the transformants had APase activity. This was confirmed by APase assays, Western blotting with 30 monoclonal antibodies to APase, and DNA sequencing of the fusion joint.

EXAMPLE 2

The following example illustrates the construction of pZIP-OUT, as disclosed in PCT Published Application Serial Number, WO 93/10246, the entire specification and figures of which are specifically incorporated herein by reference in their entirety. The plasmid was constructed from a DNA segment of *Salmonella* and a PhoA DNA segment lacking signal and expression sequences. When expressed from a host cell, the fusion protein localized to the host cell outer membrane fraction.

**PREPARATION OF pZIP-OUT EXPRESSION VECTOR**

15 Genomic DNA was isolated from *Salmonella* strain TAP43. A 25 ml culture in LB broth was grown overnight at 37°C with shaking. The cells were harvested by centrifugation, and the pellet washed once in PBS. The washed pellet was resuspended in 10 ml of cold TE buffer (10 mM Tris-HCl, pH 8.0, 1 mM EDTA). One ml of a 1 mg/ml lysozyme solution was added, and the mixture was incubated in a 37°C water bath for fifteen minutes. After this incubation, 1.2 ml of 10% sarkosyl, 5 mg/ml pronase in TE buffer was added, and incubation continued 20 at 37°C for 1-2 hours, until cell lysis occurred. The lysate was then extracted twice with an equal volume of phenol, once with phenol/chloroform, and once with chloroform. To the final extraction, a half-volume of 7.5 M ammonium acetate was added. The solution was mixed 25 gently and placed on ice. Two volumes of ice-cold absolute ethanol were layered on top of the lysate, and the chromosomal DNA was collected at the interface by spooling on a glass rod. The spooled DNA was rinsed once in 70% ethanol, and then allowed to dissolve off of the 30 glass rod into TE buffer overnight at 4°C. The buffer, containing the dissolved DNA, was then ethanol-precipitated. The purified chromosome was collected by

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centrifugation and resuspended in a small volume of TE buffer. 1-5  $\mu$ g of the purified DNA was restricted with *Hind*III, and then phenol/chloroform extracted and ethanol precipitated. The sample was collected by 5 centrifugation, the pellet washed once with 70% ethanol, and dried under vacuum.

Vector pUC18 was also restricted with *Hind*III, extracted, and precipitated in the same manner. The 10 *Hind*III fragments of the genomic DNA were then ligated into the *Hind*III site of pUC18 with T4 DNA ligase. After ligation, the DNA was transformed into competent DH5 $\alpha$  cells and plated on L-agar supplemented with ampicillin and X-P, both at 40  $\mu$ g/ml. Blue colonies, indicating the 15 presence of an active APase fusion in the transformant, were selected and analyzed by restriction mapping. Transformant #43-17 contained a 4.5 kb *Hind*III insert in the pUC18 vector. 3.1 kbp of this insert consisted of *phoA* sequences, with the remaining 1.4 kbp being derived 20 from *Salmonella* chromosomal sequences. This construct was designated pZIP-OUT.

The identity of pZIP-OUT as a *phoA* fusion was confirmed by restriction analysis, Southern hybridization 25 analysis, and finally, by DNA sequencing. The *Salmonella-phoA* fusion contained within this *Hind*III fragment was designated as the pZIP-OUT cassette. This cassette was subsequently cloned into the *Hind*III sites of the vectors pBR322 and pAT153.

30

EXAMPLE 3

The following example illustrates how DNA may be fused to the gene segments of plasmid pZIP-IN, shown in 35 this example with a portion of the cholera toxin subunit B gene.

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#### CONSTRUCTION OF pIMB13 USING THE pZIP-IN VECTOR

pIMB13 (FIG. 3) is a derivative of pZIP-IN in which the final 294 base pairs of *ctxB* have been inserted in frame with the *phoA* gene sequence at the *SspI* site. The inserted fragment containing the *ctxB* gene sequence is from pRIT10810 which encodes the entire *ctxB* gene.

5 First, the *SspI* site in the pBR322 portion of pZIP-IN was eliminated as follows. 2  $\mu$ g of a plasmid preparation of

10 pZIP-IN was digested with *Scal*I and *EcoRV*. Both enzymes cut at a single site within the pBR322 portion of the vector and generate compatible blunt ends. The digested DNA was precipitated and ligation was performed in 20  $\mu$ l of 1X ligase buffer containing 1 U of T4 DNA ligase

15 overnight at 4°C. DH5 $\alpha$ " frozen competent cells were transformed with 5  $\mu$ l of the ligation reaction mixture.

Transformants were selected on L-agar plates containing 50  $\mu$ g/ml kanamycin. Colonies were then

20 replicated to L-agar plates containing 40  $\mu$ g/ml ampicillin. Loss of ampicillin resistance encoded by pZIP-IN indicated that the segment from *Scal*I (3844) to *EcoRV* (185) which contained the *SspI* site (4168) had been eliminated. The resulting plasmid pAS28-1 contained a

25 single *SspI* site in the *phoA* sequence which generates an in-frame blunt end cut.

pIMB13 was constructed from pAS28-1 as follows. The *ctxB* sequence encoded by pRIT10810 contains an *SspI* site

30 which generates an in-frame blunt end cut near the 5' end of the structural gene. pRIT1080 also contains an *SspI* site in the pBR322 portion of the vector. Digestion of pRIT10810 with *SspI* generates 2 fragments, one of which contains the 3' final 294 base pairs of *ctxB*. 2  $\mu$ g of

35 pAS28-1 and 2  $\mu$ g of pRIT10810 were digested with *SspI*. Following phenol/chloroform extraction, the samples were combined and precipitated with 2 volumes of ethanol.

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Ligation of the sample was performed in 20  $\mu$ l of 1X ligase buffer containing 1 U T4 DNA ligase. DH5 $\alpha$  frozen competent cells were transformed with 5  $\mu$ l of the ligation mixture. Transformants were selected on L-agar 5 plates containing 50  $\mu$ g/ml kanamycin and 40  $\mu$ g/ml X-P. Colonies harboring pAS28-1 with inserts at the *phoA* *Ssp*I site appeared white since insertion interrupted the active *phoA* gene fusion. White kanamycin resistant colonies were picked for isolation and screened for 10 expression of a *ctxB* fusion protein by Western blotting of total envelope fractions with affinity purified anti-*ctxB*. A DH5 $\alpha$  strain harboring a derivative of pZIP-IN encoding a *ctxB* gene fusion was identified and the plasmid was designated pIMB13.

15

EXAMPLE 4

The following example illustrates a tripartite fusion prepared from plasmid pZIP-OUT. This plasmid may 20 be used to express a fusion polypeptide from suitable host cells. The DNA inserted in this example is a segment from cholera toxin B subunit.

**CONSTRUCTION OF A TRIPARTATE FUSION USING pZIP-OUT**

25

The construction of the trihybrid fusion, pRSP-18, was accomplished as follows. pRIT10810, containing the cholera toxin B gene, was first restricted with *Eco*RI and *Pst*I. The ends generated by these restrictions were 30 repaired with Klenow, and the vector was ligated back together. This created a 0.8 kbp deletion in pRIT10810, eliminating an undesirable *Ssp*I site in the vector. This deleted pRIT10810 was then restricted with *Hind*III and *Ssp*I. pZIP-OUT (in vector pUC18) was doubly restricted 35 with *Hind*III and *Pvu*II. A 2.0 kbp fragment generated from this double restriction, consisting of 1.4 kbp of *Salmonella* sequence and 0.6 kbp of *phoA*, was isolated and

purified after agarose gel electrophoresis. This 2.0 kbp fragment was then unidirectionally ligated into the *Hind*III/*Ssp*I digested pRIT10810. This generated an in-frame fusion of the *Salmonella-phoA* sequences to the *ctxB* sequence (pSP-18). This clone was selected on the basis of weak tetracycline resistance (1  $\mu$ g/ml in L-agar). To make further manipulations of the plasmid more efficient, a kanamycin gene block (Pharmacia) was cloned into the *Bam*HI site of pSP-18, resulting in the plasmid 10 construction pRSP-18.

#### EXAMPLE 5

This example illustrates the procedure for 15 extracting and separating bacterial membranes. After isolation of the membrane fragments, they were analyzed for localization of fusion peptides.

#### **PREPARATION OF BACTERIAL MEMBRANES (TOTAL ENVELOPE) AND 20 SEPARATION INTO INNER AND OUTER MEMBRANE FRACTIONS**

100 ml of overnight bacterial cultures grown in L-Broth with vigorous shaking were pelleted and washed 1X in phosphate buffered saline (pH 7.0). Washed pellets 25 were resuspended in 3 ml of membrane isolation buffer [10 mM NaPO<sub>4</sub>, 0.5 mM MgSO<sub>4</sub> (pH 7.0)]. Samples were sonicated for 20 seconds 3 times with cooling on ice in between. Unbroken cells were removed by centrifugation at 7,000 rpm. Then total envelopes were isolated in a Beckman 30 ultracentrifuge using an SW55 rotor at 38,000 rpm for 1 hr. The supernatants were removed and total envelope pellets were rinsed 1X in sterile deionized water. Pellets were resuspended in 40  $\mu$ l of sterile deionized 35 water. One-half (20  $\mu$ l) was saved for Western analysis of the total envelope. A 5% solution of sarkosyl in sterile deionized water was added to the remaining 20  $\mu$ l to a final concentration of 0.5%. The samples were

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incubated for 30 minutes at room temperature and centrifuged in a microcentrifuge to pellet the non-soluble fraction representing the outer membrane. The supernatant was removed for Western analysis of the inner 5 membrane fraction. The outer membrane pellet was rinsed once in sterile deionized water and saved for Western analysis. Immunoblot analysis of membrane preparations using mouse anti-APase was performed.

10

EXAMPLE 6

The following example describes the analysis of APase activity. For purposes of the present invention, APase assays were performed to test for enzyme activity 15 in membrane fractions of host cells in which alkaline fusion proteins were expressed.

**DETERMINATION OF APase ACTIVITY OF FUSION PROTEINS**

20 APase activity encoded by pZIP-IN and pZIP-OUT was confirmed by spectrophotometric assay using the chromogenic APase substrate *p*-nitrophenol phosphate (pNPP) (Table 1). One ml of overnight bacterial cultures was pelleted for 15 seconds in a microcentrifuge. The 25 pellet was washed once in 1 M Tris-HCl (pH 8.0) and resuspended in 1 ml of 1 M Tris-HCl (pH 8.0). The optical density at 600 nm of the bacterial suspension was recorded. 50  $\mu$ l of chloroform and 50  $\mu$ l of 0.1% SDS were added to permeabilize the cells. Samples were vortexed 30 briefly. 0.1 ml of a 0.4% solution of *p*-NPP in 1 M Tris-HCl (pH 8.0) was added and samples were incubated at 37°C. After development of a yellow color, 10  $\mu$ l of 2.5 M KPO<sub>4</sub> and 0.5 M EDTA was added and samples were placed on ice to stop the reaction. Cellular debris was removed 35 by centrifugation in a microcentrifuge. The optical density of the samples at 420 nm was recorded.

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Alkaline phosphatase activity was determined as described (Beckwith and Manoil, 1984). Bacteria were grown under various conditions and washed once in Tris-buffered saline (pH 8.0). Optical density (O.D.) readings at  $A_{600}$  were determined for washed bacteria resuspended in alkaline phosphatase buffer (pH 9.5). 50  $\mu$ l of SDS (0.1%) and chloroform each were added to permeabilize the cell suspension. After agitation, 100  $\mu$ l of 0.4% *p*-NPP was added. Cultures were incubated at 37°C until a substantial yellow color change occurred and 100  $\mu$ l of 1 M  $KH_2PO_4$  was added to stop the reaction. After 10 incubation, samples were centrifuged to remove any cellular debris. Absorbance readings of samples were taken at  $A_{420}$ .

15

TABLE 1

ALKALINE PHOSPHATASE ACTIVITY OF THE ANTIGEN PLACEMENT  
VECTORS, pZIP-OUT AND pZIP-IN

5	Strain <sup>a</sup>	PhoA Activity <sup>b</sup> (Units/min)
	<i>E.coli</i> CC118	11
	<i>E.coli</i> CC118(pZIP-OUT)	1037
	<i>E.coli</i> CC118(pZIP-IN)	652
	<i>E.coli</i> CC118(pUC18)	13

10

<sup>a</sup> *E.coli* CC118 is  $\Delta$ phoA. pZIP-OUT, pUC18 and pZIP-IN were introduced into CC118 by transformation. pUC18 is the parental plasmid of pZIP-OUT and pZIP-IN.

15

<sup>b</sup> Cultures were grown in L-broth overnight at 37°C with aeration and prepared for assay as reported (Beckwith and Manoil, 1985).

Activity was determined by:

$$\text{Activity(units/min)} = \frac{OD_{420}}{OD_{600} \times \text{time}} \times 1000$$

20

An immunoblot analysis of urea extracts using anti-APase as the primary antibody was performed. No reaction was shown with plasmid pER322 or with plasmid pZIP-IN. A reaction was shown with plasmid pZIP-OUT, indicating extraction of the APase.

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EXAMPLE 7

The following outlines the general procedure for extracting proteins from bacterial cells.

5

**UREA EXTRACTION OF BACTERIAL CELLS**

Ten ml of overnight stationary phase bacterial cultures grown in L broth with vigorous shaking were 10 cooled on ice for 10 minutes and pelleted at 7,000 RPM in a Beckman J2-21 (JA-17 rotor). The bacterial pellet was washed 3 times in phosphate buffered saline (pH 7.0). The washed pellet was resuspended in 0.1 ml of 6 M urea containing 10 mM Tris-HCl (pH 7.5) and 5 mM EDTA. The 15 suspension was incubated for 20 minutes on ice. Bacteria were pelleted in a microcentrifuge for 1 minute. Centrifugation of the supernatants was repeated to remove any traces of debris. Supernatants were frozen and 20  $\mu$ l aliquots were used for SDS-PAGE and Western analysis.

20

EXAMPLE 8

The following example illustrates the expression of a cholera toxin subunit B (CtxB) polypeptide from an 25 attenuated *Salmonella* strain with localization of the CtxB to the surface of the outer cell membrane.

**PREPARATION OF SURFACE EXPRESSED CHOLERA TOXIN SUBUNIT B**

30 The tribrid fusion in pRSP-18 contains a 1.4 kb *Salmonella* DNA sequence which encodes the expression export signals of the expressed gene. The *phoA* sequence of the fusion includes approximately 0.6 kb from the Tn*phoA* fusion joint (FJ) to the in-frame insertion (IF) 35 of *ctxB*. The *ctxB* sequence includes the final 294 base pairs of *ctxB* beginning at the in-frame insertion site IF. Expression and export result in a 32 kDa tribrid

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fusion protein including the final 98 amino acids of *ctxB* at the C-terminus which localizes to the outer membrane. The tribrid fusion in a pIMB13, contains a 1.3 kb *Salmonella* DNA sequence which encodes the expression and 5 export signals of the expressed gene. The *phoA* sequence of the fusion includes approximately 0.2 kb from the Tn*phoA* fusion joint FJ to the inframe insertion IF of *ctxB*. The *ctxB* sequence includes the final 294 base pairs of *ctxB* beginning at the inframe insertion site IF. 10 Expression and export result in a 32 kDa tribrid fusion protein including the final 98 amino acids of *ctxB* at the C-terminus which localizes to the inner membrane.

Whole *Salmonella* TA2362 cells harboring pRSP-18 were 15 shown to express cholera B subunit on the outer surface membrane. Antisera to cholera toxin B subunit were prepared. Agglutination of TA2362 harboring pRSP-18 was obtained. No agglutination was observed with strain TA2362 alone, Table 2.

20

EXAMPLE 9

The following example illustrates the procedures contemplated as useful for creating an immune response in 25 a mammal elicited with virulence attenuated *Salmonella* strains expressing antigens on the surface of the intact cell. In this example, CTB is used as an illustration.

**IMMUNOGENIC RESPONSES FROM SURFACE-EXPRESSED CTB**

30

Ten C57/B16 mice were orally challenged with a virulence-attenuated *S. typhimurium* *aroA phoN* strain, G361, harboring pRSP-18 and ten C57/B16 mice were challenged with the same straining harboring a plasmid 35 which expresses CTB cytosolically (pRIT108010, ATCC-39051) produced CTB-specific antibodies after immunization (Table 2).

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The results using I.P. challenge ( $5 \times 10^5$  cfu) and oral challenge ( $5 \times 10^8$  cfu) were evaluated. Boosting was 10 days post-challenge. Mucosal and serum anti-CTB levels were determined after 1° and 2° challenge by ELISA and by the ability to neutralize cholera toxin activity on adrenal cells (Majarian et al., 1989). It was determined whether the membrane-expressed CTB tribrid polypeptide retained its potent mucosal adjuvant activity (Tagliabue, 1989) by comparing antibody titers to 5 *Salmonella* and *Salmonella* expressing CTB. Since CTB mediates Ig class switching, IgA/IgG ratios were determined between the different challenge protocols by 10 ELISA. Alternatively, the adjuvant activity of membrane expressed CTB were evaluated using a purified antigen 15 (i.e., ovalbumin) for concurrent challenge with *Salmonella* or *Salmonella* expressing CTB strains.

To account for the low expression of pRIT10810 in *Salmonella*, ~3X the bacterial challenge dose of this 20 strain was utilized. While this may not represent an optimal comparison, significantly higher titers were observed after challenge with *Salmonella* harboring PRSP-18, the surface-encoded CTB strain. These data suggest that antigens present in different subcellular 25 compartments are not equally "seen" by the immune system and that the placement of epitopes on the bacterial surface represent an optimal method for vaccine development.

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TABLE 2

$\alpha$ CTB TITERS FROM MICE CHALLENGED ORALLY WITH  
*S. TYPHIMURIUM* EXPRESSING CTB IN VARIOUS  
 SUBCELLULAR LOCATIONS

5	Plasmid <sup>a</sup>	Subcellular Location of Expressed CTB	ELISA Titer <sup>b</sup>
	None		<4
	pRIT10810	Cytosolic	17
	pRSP-18	OM surface	210

10 <sup>a</sup> *S. typhimurium* G361 (aroA) harboring no plasmid or as indicated. Overnight cultures of G361 harboring pRSP-18 ( $2.1 \times 10^8$  CFU) were used for oral challenge. For G361 harboring pRIT10810, the challenge dosage was  $5.8 \times 10^8$  CFU.

15 <sup>b</sup> Reciprocal of dilution giving OD = 1.0 in ELISA. Wells were coated with GM<sub>1</sub>-ganglioside followed by cholera toxin. Mice were bled by the tail vein 12 days post-challenge. Results are the average of 5 wells.

20 Anti-CTB activity is additionally assessed for the ability to neutralize the biological activity of cholera toxin (CT). CTB-specific antibodies of various isotypes have been shown to neutralize the CT biological activity 25 (Lycke et al., 1985). Serum dilutions are incubated with various concentrations of CT at 25°C for 1 hr, with purified CTB-specific antibodies serving as controls. Neutralization of CT is assessed by inhibition of CHO cell elongation, (Guerrant et al., 1974). Dilutions of 30 commercial CT and CTB-specific antisera are used to standardize this assay.

35 To demonstrate that CTB on the surface of the *Salmonella* OM leads to the induction of protective immunity which abrogates CT activity *in vivo*, ligated ileal loops may be constructed. Many studies to define

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the molecular mechanism(s) of action of CT have utilized this model. For these studies, groups of mice are challenged orally with: a) *Salmonella/pRIT10810*; b) *Salmonella/pRSP-18*; c) CTB (10-100  $\mu$ g); d) PBS, or e) 5 *Salmonella* alone. Effectiveness of the immunization is followed by determining serum titers to CTB. Ligated ileal loops (2 x 5 cm) are placed in immunized mice and challenged with various levels of purified CT (0-50  $\mu$ g) for various times (6-24 hrs). Effectiveness of CT- 10 neutralizing activity is assessed by measuring cAMP level in intestinal tissue (Guerrant et al., 1974) and measuring luminal fluid accumulating in the ligated loop at 6-24 hrs postchallenge. Protection by 15 *Salmonella/pRSP-18* shows that OM CTB expression is effective in producing protective immunity.

Mice challenged i.p. with purified CTB and a *Salmonella* strain expressing a CTB fusion protein are assessed for in vitro T cell activation. At ten and 20 twenty days following i.p. challenge, purified splenic T cells are assessed for proliferation following in vitro stimulation with the following: a) *Salmonella* porin, b) whole cell lysates of the *Salmonella* CTB and CTB fusion expressing strains, c) whole cell lysates of *E. coli* D- 25 12, d) CTB or e) PBS. Splenic T cells are assessed using microtiter cultures as previously described (Ramarathinan et al., 1991). Peritoneal macrophages are used as antigen-presenting cells. In these studies, macrophages ( $2.5 \times 10^4$ /well) are pulsed with different concentrations 30 of test antigen for 2 hrs and washed before T cells ( $2 \times 10^5$ /cells) are added to cultures. Cultures are assessed for proliferation at 2-4 days using [ $^3$ H]-thymidine incorporation.

EXAMPLE 10

This example illustrates insertion of a fragment of HIV  $\Delta$ gp160 gene into pZIP-OUT of Example 2.

5

**CONSTRUCTION OF pZIP-OUT2 ENCODING A 60 kDa  
FRAGMENT OF HIV  $\Delta$ GP160**

The present invention also includes construction and 10 characterization of a pZIP-OUT derivative which expresses HIV  $\Delta$ gp160 (gp120/gp41) epitopes in *Salmonella*. gp120 and gp41 are produced by the cleavage of the precursor gp160 molecule (Hu et al., 1986). This gene was chosen because: 1) AIDS continues to be a major public health 15 problem; 2) effective mucosal immunity may play a significant role in early host protection to HIV; 3) extensive information has accumulated as to the structure and function of this gene and its product. gp120 mediates HIV interaction with human CD4 cells (LaRosa 20 et al., 1990). In this regard, the predominant neutralizing determinant (PND) of HIV (LaRosa et al., 1990) is located on the V3 loop of pg120; 4) antibodies to gp120 and gp41 are commonly observed in the sera of infected individuals; 5) mutation studies and 25 competition studies with synthetic peptides (McPhee et al., 1990) have shown that gp120 and gp41 interaction is required for viral infectivity. Thus, antibody binding to the PND or in the region of gp120-gp41 interaction will disrupt viral replication; and 6) 30 purified recombinant gp120 and gp160 are currently under investigation as vaccine candidates.

A clone containing a 3.1 kb *Sal*I-*Xba*I fragment encoding the HIV gp160 gene was obtained from Dr. M. 35 Cloyd (Department of Microbiology and Immunology, University of Texas Medical Branch, Galveston, TX). *Pvu*II digestion of this fragment yielded a 1.8 kb

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fragment that deleted 0.7 kb of gp120 coding sequence. The 4.5 kb pZIP-OUT cassette, bounded by *Hind*III sites, was cloned into the *Hind*III site of vector pAT153 ( $\Delta$ *Pvu*II site). This construction has been designated pZIP-OUT-2.

5 pZIP-OUT-2 was digested with *Pvu*II and *Sal*I, and the *Pvu*II - *Xho*I HIV fragment ligated into these sites. The tribrid fusion polypeptide from this construction yielded a 82 kDa polypeptide (2-4 kDa, *Salmonella*; 20 kDa, *phoA*; and 60 kDa,  $\Delta$ gp160).

10

Western analysis of outer membrane preparations of *Salmonella* harboring pAH13 was performed (FIG. 1). An immunoblot probed with an anti-gp120 polyclonal antibody showed a *Salmonella*::*PhoA*:: $\Delta$ gp160 fusion protein having a 15 molecular mass of 84 kDa, the predicted value.

Both IgG and IgA antibody responses to gp120/gp41 may be determined from serum and extracts from intestinal scrapings. Antibodies to gp120/gp41 are detected by 20 immunoblotting on separated viral proteins and level of antibodies determined by a quantitative HIV assay or a trans-activation assay. In this assay, pre-titered HIV stocks (treated and parallel untreated controls) are serially diluted in appropriate buffers and inoculated 25 into individual wells of a 48-well tissue culture plate containing  $10^5$  CD4 $^+$  cells suspended in 200  $\mu$ L of culture medium containing 3  $\mu$ g/mL polybrene. After 48 hours, an additional 100  $\mu$ L of medium containing 30  $\mu$ g dextran sulfate/mL is added to inhibit extracellular viral 30 spread. Five days after inoculation, cells are assayed using a fixed-cell IFA with M26 monoclonal antibody (MoAb). The percentage of cells staining positive for viral core antigen p24, relative to cells infected with untreated HIV at a given dilution of virus reflects the 35 decrease of infectivity in treated virus. Alternatively, dilutions of HIV may be inoculated into a CD4 $^+$  cell line, H938, carrying an integrated copy of the HIV-1 long

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terminal repeat (LTR) linked to the chloramphenicol acetyltransferase (CAT) gene (Felber and Paulakis, 1988). Thirty-six to 48 hours post-infection, cells are washed, lysed, and assayed for CAT activity using a commercially available kit. The highest dilution of virus showing enhanced CAT activity, when compared to cells infected with untreated HIV, allows quantitative assessment of the antiviral effect of a compound. Results from these studies reveal whether mucosal and/or systemic antibodies result from immunization of mice with a *Salmonella* surface-expressed  $\Delta$ gp160 fusion protein.

EXAMPLE 11

15

DNA SEQUENCING OF FUSION VECTORS

pZIP-IN, pZIP-OUT, and pRSP-18 were sequenced by the Sanger dideoxy protocol for double stranded DNA templates.

20

Preparation of Templates

Purified plasmid preps for sequencing were prepared as follows:

25

1. Each strain was grown overnight in 5 ml of LB broth (containing the appropriate antibiotic) at 37°C with vigorous aeration.
2. The cultures were harvested by centrifugation. The cell pellets were resuspended in 100  $\mu$ l of 50 mM glucose, 10 mM EDTA, and 25 mM Tris-HCl, pH 8.0, and incubated at room temperature for 5 minutes.
3. 200  $\mu$ l of freshly prepared .2N NaOH, 1% SDS were added to each sample. The samples were mixed by inversion, and then incubated 5 minutes on ice.

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4. 50  $\mu$ l of 3 M potassium acetate (pH 4.8) were added to each sample. The samples were mixed by inversion and incubated for 5 minutes on ice.
5. The samples were then centrifuged for 5 minutes, and the supernatants transferred to fresh tubes. The samples were centrifuged a second time for 5 minutes and the supernatants transferred as before.
10. RNase A was added to a concentration of 20  $\mu$ g/ml, and the samples were incubated at 37°C for 20 minutes.
15. Each sample was phenol/chloroform extracted, chloroform extracted, and then ethanol-precipitated.
20. The DNA precipitates were collected by centrifugation and each DNA pellet was resuspended in 16  $\mu$ l deionized water, 4  $\mu$ l 4 M NaCl, and 20  $\mu$ l 13% polyethylene glycol 8000. The samples were mixed well and incubated on ice for 20 minutes.
25. The samples were centrifuged 10 minutes and the supernatants discarded. The pellets were washed twice in 70% ethanol, dried, and resuspended in 20  $\mu$ l of dH<sub>2</sub>O.

#### **Denaturation, Annealing, and Sequencing of Templates**

For each DNA template prepared as above:

30. 1. 2  $\mu$ l of 2 M NaOH/2 mM EDTA were added to the entire 20  $\mu$ l sample and the sample was incubated for 10 minutes at room temperature.
2. The reactions were neutralized by the addition of 4.5  $\mu$ l of 2 M sodium acetate (pH 5.0) and 5.5  $\mu$ l of dH<sub>2</sub>O. The samples were mixed well, and then precipitated with 100% ethanol.

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3. The DNA pellets were collected by centrifuging for 15 minutes. The pellets were then washed once with 70% ethanol and dried.
4. All of the following reagents, except primers and radioactive label, were supplied in the Sequenase™ sequencing kit (Amersham Corp., Arlington Heights, IL). The dried pellets were resuspended in 7  $\mu$ l dH<sub>2</sub>O, 2  $\mu$ l of 5X Sequenase reaction buffer and 1  $\mu$ l (~20 ng) of the appropriate primer. For sequencing the *Salmonella* sequences in pZIP-IN and pZIP-OUT, immediately upstream from the *phoA* junction, primer 1 was used. For extended sequencing in the *Salmonella* sequences of pZIP-OUT, primer 2 was utilized. To sequence across the *phoA:ctxB* junction in pRSP-18, primer 3 was used. The annealing reactions were incubated for 30 minutes at 37°C.
5. To each annealing mixture, 2  $\mu$ l of .1M dithiothreitol, 2  $\mu$ l of diluted labelling mix, 1  $\mu$ l of [ $S^{35}$ ]-dATP, and 2  $\mu$ l of diluted Sequenase™ enzyme were added. The reactions were mixed and incubated at room temperature for 5 minutes.
6. 3.5  $\mu$ l of each labelling reaction were then transferred to each termination mixture tube, containing dideoxy ATP, dideoxy GTP, dideoxy CTP, and dideoxy TTP. The chain termination reactions were allowed to proceed for 5 minutes at 37°C.
7. 4  $\mu$ l of stop solution were added to each reaction, and the reactions were heated to 75°C for 2-5 minutes.
8. The reactions were loaded onto a 6% acrylamide-urea sequencing gel and electrophoresed at 15 mA for 2-6 hours.

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9. After electrophoresis, the sequencing gel was fixed in 10% methanol, 10% acetic acid, for 1 hour and then dried under vacuum for 1 1/2 hours.
- 5 10. The dried gel was then exposed to autoradiograph film at room temperature for ~16 hours.

EXAMPLE 12

10

This example illustrates insertion of a fragment of influenza HA epitope into pZIP-OUT vector of Example 2.

15

**CHARACTERIZATION OF PLASMIDS EXPRESSING INFLUENZA  
HEMAGGLUTININ EPITOPES AND THEIR USES FOR  
INFLUENZA VACCINES**

20 The present invention describes the construction and characterization of export-specifying plasmids which express influenza strain A/PR/8/34 hemagglutinin (HA) epitopes in the surface of a virulence-attenuated *Salmonella* strain.

25 These strains were constructed using pZIP-OUT.

30 It is well established that HA of influenza is a critical viral structure for immune defense mechanisms (Stuart-Harris, 1979). Antibodies to HA are produced during natural infection (Schulman, 1975) and after vaccination (Schulman, 1975). A number of studies have shown that it is antibody to HA which blocks infection *in vitro* and *in vivo* (Stuart-Harris, 1979; Schulman, 1975). Thus, antibody to HA is a critical component in antiviral immunity to influenza virus.

35

HA mediates the absorption and penetration of influenza virus into susceptible cells, and hence, is

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well established as an critical target for immune defense mechanisms (Wilson et al., 1981; Stuart-Harris, 1979). In these studies, the consequence of immunization with *Salmonella*-expressed HA is investigated on the ability of 5 mice to mount an effective host defense to influenza virus A/PR/8/34. At various times post-boost (10-21 days), groups of immunized mice are challenged intranasally with 3-30 LD50 or 1-10 MPD50 (mouse pneumonia dose) of influenza virus. The effectiveness of 10 the various immunization protocols is evaluated by a comparison of survival in the lethality studies and a comparison of the pneumonic consolidation lesion scores (Gerone et al., 1971). These results are evaluated in the context of the antibody titers and for significance 15 using an appropriate statistical model.

The influenza HA1 gene chosen for these studies because: 1) it is readily available (American Type Culture Collection, 1990, #39736); 2) it is of optimal 20 size for these genetic manipulations and has been completely sequenced (Caton et al., 1982); 3) it contains immunodominant regions (HA1) which have previously been identified (Green et al., 1982) and correlated with topographically distinct regions on the surface of the 25 polypeptide (Wilson et al., 1981); 4) it is well established that HA is a critical target structure for humoral immune defense (Stuart-Harris, 1979); 5) it is known that mucosal immunity is essential to effective host defense; and 6) an exquisitely sensitive, murine 30 animal model is available to assess immunity to influenza virus (Gerone et al., 1971). Thus, HA fusion polypeptides expressed on *Salmonella* vaccine strains used to orally immunize mice represent an ideal model. Such *Salmonella* strains have utility as influenza vaccine 35 candidates. Advantages of this recombinant vaccine are increased stability, low cost, and elimination of costly purification protocols used with the current vaccine.

**Generation of the *Salmonella*::HA1 Gene Fusion**

The cloned HA1 gene from influenza virus A/PR/8/34 was utilized. This gene and the parental virus from 5 which it was derived are available from ATCC (American Type Culture Collection, 1990, #39736). Gene fusions into pZIP-OUT utilized methods analogous to those described hereinabove for *ctxB* (CTB). Specifically, HA1 DNA sequences were restricted with *Hpa*I at position 175 10 (Caton et al., 1982), and blunt end ligated into the *Ssp*I or *Pvu*II site of pZIP-OUT. This joined the HA1 polypeptide to the *Salmonella* export sequences at residue 30 (Asn) and resulted in a fusion protein which retains 295 of the 325 HA1 amino acids (Caton et al., 1982). 15 This strategy insures the retention of the operationally distinct Sa, Sb, Ca, and Cb antigenic sites of HA (Caton et al., 1982; Green et al., 1982; Wilson et al., 1981). The continuity of the reading frame across the fusion joints was confirmed by DNA sequencing.

20

**Western Analysis of Resulting Fusion Protein**

Expression of appropriate fusion polypeptides were evaluated by immunoblot analysis using HA-specific 25 antibodies. Membrane expression of the fusion polypeptides was confirmed by observation of the predicted 43 kDa fusion polypeptide in isolated OM fractions (Fillip et al., 1973). To determine if surface-expressed HA is biologically active on the 30 *Salmonella* surface, *Salmonella* harboring the pZIP-OUT vector alone, the HA1-encoding pZIP-OUT derivative, and a control strain were characterized for hemagglutinin or hemagglutination inhibition (Gerone et al., 1971) activity.

EXAMPLE 13

This example illustrates insertion of a fragment of SFG rickettsial outer membrane p190 into the pZIP-OUT vector of Example 2.

**CHARACTERIZATION OF PLASMIDS EXPRESSING  
SFG RICKETTSIAL OM p190 EPITOPEs**

10 In this example, the inventors contemplate the construction of a pZIP-OUT derivative which expresses SFG rickettsial outer membrane (OM) p190 (Anderson et al., 1990) epitopes. A 1.87 kb *NaeI-HpaI* fragment which contains the sequence representing the species-specific 15 epitope (Anderson et al., 1990) has been constructed. Retention of an open reading frame for the construct may be confirmed by DNA sequencing across the fusion joint. plasmids may then be introduced into *Salmonella* by electroporation. Expression of the predicted fusion 20 polypeptides is evaluated by immunoblot analysis using SFG p190 sera. The membrane localization of the fusion protein is then determined by immunoblot analysis following fractionation of the *Salmonella* strains to yield OM, total envelope, and inner membrane fractions 25 (Fillip et al., 1973). Finally, surface preparations may be assessed for immunoreactive epitopes.

EXAMPLE 14

30 Several different types of heterologous proteins have been successfully directed to the outer membrane of *Salmonella*. The vector employed was pZIP-OUT. Included are an ~85 kDa tribrid fusion protein encoded by 1.8 kb HIV Agp160 gene segment, ~52 kDa and ~68 kDa fusion 35 polypeptides encoded by a 1.1 kb and a 1.6 kb gene segment of the influenza virus hemagglutinin gene and a

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32 kDa CTB fusion protein. All polypeptides were found in OM fractions. These data are summarized in Table 3.

5 pZIP-OUT represents an export-directing vector that transports the products of diverse heterologous gene segments to the *Salmonella* OM.

EXAMPLE 15

10 To show that the plasmid-encoded *Salmonella* export sequences direct APase fusion proteins to the cell envelope, subcellular fractions of *Salmonella* strains harboring pZIP-IN or pZIP-OUT were prepared to yield total envelope (TE), OM and IM preparations. These were 15 utilized for Western analysis and probed with a MoAb to APase. An APase fusion protein in pZIP-OUT-containing cells was observed at high levels in the OM and TE, while only trace amounts were present in the IM. For pZIP-IN containing cells, an APase fusion protein was observed in 20 the IM and TE while only trace amounts were seen in the OM.

25 In other studies, surface-encoded polypeptides were extracted from *S. typhimurium* harboring either pZIP-IN or pZIP-OUT by mild urea extraction. In Western analysis of these surface extracts probed with a MoAb to APase, only pZIP-OUT showed surface expression of an APase fusion protein, indicating that APase is directed to the IM or OM by export-specifying motifs of pZIP-IN and pZIP-OUT, 30 respectively.

TABLE 3  
SUMMARY OF THE SUBCELLULAR LOCALIZATION OF FUSION  
POLYPEPTIDES EXPRESSED BY EXPORT-DIRECTING PLASMIDS

5	Plasmids <sup>a</sup>	Expressed fusion polypeptide <sup>b</sup>	Subcellular localization of fusion polypeptide in: <sup>c</sup>				
			CYT	TE	IM	OM	SURF
	pZIP-IN	APase	-	+	+	-	-
	pZIP-OUT	APase	-	+	-	+	+
	pIMB13	Δ APase + CTB	-	+	+	-	-
10	pRSP-18	Δ APase + CTB	-	+	-	+	+
	pBDHA1.6	Δ APase + HA	+	+	-	+	ND
	pBDHA1.1	Δ APase + HA	+	+	-	+	ND
	pAH13	Δ APase + Δgp160	+/-	+	-	+	ND

15       <sup>a</sup> pBDHA1.1 and pBDHA1.6 are derivatives of pZIP-OUT and express a 52 kDa and 68 kDa influenza virus hemagglutinin fusion protein, respectively, pAH13 is a derivative of pZIP-OUT which expresses a fusion protein which is ~85 kDa which contains ~20 kDa of HIV sequence, all of gp41 and export-specifying and PHOA sequences.

20       <sup>b</sup> Composition of hybrid polypeptides containing *Salmonella* export sequences. (Δ-deletion, AP-APase; HA-influenza virus hemagglutin; Δgp160-human immunodeficiency virus polyprotein with Δgp120 and gp41 sequences).

25       <sup>c</sup> CYT (cytosolic fraction) TE (total envelope). IM (inner membrane) and OM (outer membrane) were separated by sarkosyl extraction (Fuhrman and Cebra, 1981). SURF (surface extractions) were prepared by urea solubilization (Manoil and Beckwith, 1986). APase or CTB were detected by Western analysis. HA and Δgp160 fusion proteins were detected by immunoblotting using commercially obtained MoAb; Δgp160 MoAB (AMAC, Inc; Westbrook, ME); HA MoAB; (O.E.M. Concepts Inc., Boston, MA).

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The ability of the pZIP-IN and pZIP-OUT to facilitate envelope expression of large segments of other genes (X) was also evaluated. These studies utilized sites within the *phoA* gene which maintain the correct 5 reading frame to produce *Salmonella:PHOA:X* tribrid fusion proteins. Using this approach, the *V. cholera* *ctxB* gene that encodes CTB was introduced into restriction sites in the *phoA* gene of pZIP-IN and pZIP-OUT that maintained the reading frame from *phoA* into *ctxB*. Both constructs 10 predict a 32 kDa tribrid fusion product containing *Salmonella*, *phoA* and virtually the entire sequence of CTB. Western analysis of whole cell extracts using a CTB-specific antisera showed that this fusion product was expressed. pRSP-18 and pIMB13 are derived from pZIP-OUT 15 and pZIP-IN, respectively.

CTB fusion proteins were observed in association with IM and OM fractions of TA1972 harboring pIMB13 and pRSP-18, respectively. Purified OM from TA2362 20 containing pRSP-18 shows the presence of a 32kDa polypeptide that was recognized by antisera to CTB. IM from this strain showed no CTB cross-reactive polypeptide. However, in TA2362 harboring pIMB13, a cross-reactive 32kDa band with this same antisera was 25 present only in TE and IM fractions, and not in OM fractions. In addition, only surface extracts from pRSP-18 harboring cells showed a 32 kDa-reactive band.

Further studies were conducted to determine whether 30 or not the 32kDa surface-expressed CTB-fusion protein encoded by pRSP-18 was released into the medium during the growth of this strain. Concentrated culture supernatants from TA2362 harboring pRSP-18, pIMB13 or no plasmids did not show the presence of the 32 kDa fusion 35 protein by immunoblotting. These data indicated that the 32kDa fusion proteins encoded by pRSP-18 and pIMB13 were not released in detectable quantities during *in vitro*

growth. In a single preliminary experiment, *Salmonella* strains harboring pRSP-18, pIMB13 or no plasmids were placed in ligated murine ileal loops for 8 hr. A 32 kDa polypeptide band was not observed in clarified intestinal 5 fluid and/or washings from loops infected by any of the strains by immunoblot analysis.

CTB epitopes on live TA2362 harboring pRSP-18 were also demonstrated. Antisera to CTB agglutinated TA2362 10 pRSP-18, but not this strain alone or TA2362/pIMB13, indicating that CTB expressed by pRSP-18 is exposed on the surface of the cell and that the tribrid fusion protein encoded by pIMB13 is associated with the IM.

15 Whole cells and cultures supernatants were prepared from *S. typhimurium* TA2362 alone and TA2362 harboring pIMB13 and pRSP-18. Cells from overnight cultures (50  $\mu$ l) and supernatants (concentrated 12.5-fold by ultrafiltration) were denatured in SDS-sample buffer, 20 separated in denaturing 10% PAG and transferred to nitrocellulose. Blots were probed with affinity-purified CTB-specific antibodies (1/500) followed by goat anti-rabbit horseradish peroxidase-conjugated antibodies (1/4000) and bands visualized by fluorography using 25 enhanced chemiluminescence (ECL, Amersham Corp., Arlington Heights, IL) development. Kodak XAR film was exposed for 45 sec. Lanes: A, TA2362, whole cell extracts (WC); B, TA2362, concentrated supernatants (CS); C, TA2362(pIMB13) WC extract; D, TA2362(pRSP-18) CS; E, 30 TA2362(pIMB13) WC extract; F, TA2362(pIMB13) CS. A CTB-reactive 32 kDa fusion protein is seen only in WC extracts (lanes C and E) and not in CS. The 32kDa fusion protein is shown with an arrow. A nonspecific protein band (~30 kDa) was observed in all WC extracts (lanes A, 35 C and E) and is shown by the X.

EXAMPLE 16

5 The inventors contemplate the use of the present system in raising antibodies to peptides or polypeptides (Martineau et al., 1991). These methods would be valuable in that the peptide or polypeptide would not need to be purified and screening of these antibodies may utilize the surface-expressed antigens.

10 **GENERATING ANTIBODIES TO FUSION PEPTIDES OR POLYPEPTIDES AND THE DETECTION THEREOF**

15 An antibody can be a polyclonal or a monoclonal antibody. In a preferred embodiment, an antibody is a monoclonal antibody. Means for preparing and characterizing antibodies are well known in the art (See, e.g., *Antibodies "A Laboratory Manual,"* E. Howell and D. Lane, Cold Spring Harbor Laboratory, 1988).

20 Briefly, a polyclonal antibody is prepared by immunizing an animal with an immunogen comprising a polypeptide of the present invention and collecting antisera from that immunized animal. A wide range of animal species can be used for the production of 25 antisera. Typically an animal used for production of anti-antisera is a rabbit, a mouse, a rat, a hamster or a guinea pig. Because of the relatively large blood volume of rabbits, a rabbit is a preferred choice for production of polyclonal antibodies.

30

35 Antibodies, both polyclonal and monoclonal, specific for the surface-expressed polypeptides and/or proteins of the present invention may be prepared using conventional immunization techniques, as will be generally known to those of skill in the art. A composition containing antigenic epitopes of the surface-directed polypeptide can be used to immunize one or more experimental animals,

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such as a rabbit or mouse, which will then proceed to produce specific antibodies against the surface-directed polypeptide. Polyclonal antisera may be obtained, after allowing time for antibody generation, simply by bleeding 5 the animal and preparing serum samples from the whole blood.

To obtain monoclonal antibodies, one would also initially immunize an experimental animal, often 10 preferably a mouse, with an antigenic composition. One would then, after a period of time sufficient to allow antibody generation, obtain a population of spleen or lymph cells from the animal. The spleen or lymph cells can then be fused with cell lines, such as human or mouse 15 myeloma strains, to produce antibody-secreting hybridomas. These hybridomas may be isolated to obtain individual clones which can then be screened for production of antibody to the desired surface-directed polypeptide.

20 Following immunization, spleen cells are removed and fused, using a standard fusion protocol (see, e.g., The Cold Spring Harbor Manual for Hybridoma Development, incorporated herein by reference) with plasmacytoma cells 25 to produce hybridomas secreting monoclonal antibodies against the surface-directed polypeptide. Hybridomas which produce monoclonal antibodies to the selected antigens are identified using standard techniques, such as ELISA and Western blot methods.

30 Hybridoma clones can then be cultured in liquid media and the culture supernatants purified to provide the fusion protein-specific monoclonal antibodies.

35 It is proposed that the monoclonal antibodies of the present invention will find useful application in standard immunochemical procedures, such as ELISA and

Western blot methods, as well as other procedures which may utilize antibody specific to the fusion protein epitopes.

5       Antibodies generated against surface-directed polypeptides will also be useful in immunolocalization studies to analyze the distribution of fusion proteins on the bacterial surface. The operation of all such immunological techniques will be known to those of skill 10 in the art in light of the present disclosure.

Surface-expressed polypeptides may also be used to detect antibodies. The bacterium would function as a solid phase support. This could have high utility for 15 diagnostic kits to detect and diagnose infectious agents or other disease states (i.e. Grave's disease) which result in the production of specific antibodies. Alternatively, surface-expressed polypeptides or peptides may be used analogously to bacteriophage display 20 libraries (Barbas et al., 1991).

The compositions of the present invention will find great use in immunoblot or western blot analysis. Antibodies generated against the surface-expressed 25 polypeptides may be used as high affinity primary reagents for the identification of proteins immobilized onto a solid support matrix, such as nitrocellulose, nylon or combinations thereof. In conjunction with immunoprecipitation, followed by gel electrophoresis, 30 antibodies to the surface-expressed polypeptides may be used as a single step reagent for use in detecting antigens against which secondary reagents used in the detection of the antigen cause an adverse background. This is especially useful when the antigens studied are 35 immunoglobulins (precluding the use of immunoglobulins binding bacterial cell wall components), the antigens studied cross-react with the detecting agent, or they

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migrate at the same relative molecular weight as a cross-reacting signal.

It is also useful in the amplification of the signal  
5 or means of detection, by providing a means of amplifying  
the chromogenic signal, for example, by allowing for  
specific binding of numerous enzyme-conjugated anti-  
surfaced-expressed polypeptide antibodies to multiple  
fusion protein or native molecules attached to the  
10 antibody. This amplification is useful regardless of the  
method of visualization. Although not necessary to the  
routine practice of the present invention, it is  
contemplated that different detection techniques may be  
employed advantageously in the visualization of each of  
15 the antigens being detected. Immunologically-based  
detection methods for use in conjunction with western  
blotting include enzymatically-, radiolabel-, or  
fluorescently-tagged secondary antibodies against the  
toxin moiety are considered to be of particular use in  
20 this regard.

It is also envisioned that antibodies expressed on  
the surface of bacteria may be selected with appropriate  
antigens by bacterial display techniques (Fuchs et al.,  
25 1991).

#### EXAMPLE 17

#### **SURFACE EXPRESSION OF ENZYMATIC PROPERTIES OF 30 FUSION PROTEINS**

The inventors further contemplate the engineering of  
surface-expressed polypeptides to allow for surface-  
expression of their enzymatic properties. Bacteria  
35 harboring these constructs may be used as biocatalysts in  
applications in which the bacterial cell is used as a  
solid support (Kessler, 1981). This may lead to use in

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diverse applications such as industrial processes to produce specific compounds to likely bioremediation applications. Other activities of the surface-expressed polypeptides could also be exploited. For example,  
5 polypeptides that bind specific molecules could be used to isolate or quantitate these molecules. In this regard, surface-expression of a receptor would allow convenient isolation of the molecule which is bound from diverse or complex sources such as bodily fluids or from  
10 the environment. An analogous, albeit more limited system which is currently used, is the protein A molecule of *Staphylococcus aureus* that functions as a receptor for immunoglobulins (Ig) and is useful in their quantitation and purification.

15

EXAMPLE 18

THE UTILITY OF SURFACE-EXPRESSION FUSION PROTEINS  
IN IMMUNOAFFINITY CHROMATOGRAPHY

20

The fact that *Salmonella* peptide sequences are present at the N-termini of surface-expressed fusion proteins generated by the methods described herein also suggests the utility of the fusion proteins of the  
25 present invention in efficiently purifying polypeptides by immunoaffinity chromatography. Antibodies directed to the *Salmonella* sequences immobilized on a column could be used in a general protocol to purify a wide range of fusion proteins which harbor this *Salmonella* export-  
30 directing sequence. These methods would be of high significance for low abundance proteins. The methods for immunoaffinity chromatography are well known to those skilled in the art (Harlow and Lane, 1988).

35 Affinity chromatography is generally based on the recognition of a protein by a substance such as a ligand or an antibody. The column material may be synthesized

by covalently coupling a binding molecule, such as an activated dye, for example to an insoluble matrix. The column material is then allowed to adsorb the desired substance from solution. Next, the conditions are 5 changed to those under which binding does not occur and the substrate is eluted. The requirements for successful affinity chromatography are that the matrix must adsorb molecules, the ligand must be coupled without altering its binding activity, a ligand must be chosen whose 10 binding is sufficiently tight, and it must be possible to elute the substance without destroying it.

\* \* \*

15 All of the compositions and methods disclosed and claimed herein can be made and executed without undue experimentation in light of the present disclosure. While the compositions and methods of this invention have been described in terms of preferred embodiments, it will 20 be apparent to those of skill in the art that variations may be applied to the composition, methods and in the steps or in the sequence of steps of the method described herein without departing from the concept, spirit and scope of the invention. More specifically, it will be 25 apparent that certain agents which are both chemically and physiologically related may be substituted for the agents described herein while the same or similar results would be achieved. All such similar substitutes and modifications apparent to those skilled in the art are

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deemed to be within the spirit, scope and concept of the invention as defined by the appended claims.

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5

The references listed below are incorporated herein by reference to the extent that they supplement, explain, provide a background for or teach methodology, techniques and/or compositions employed herein.

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SEQUENCE LISTING

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20 (iii) TITLE OF INVENTION: MEMBRANE EXPRESSION OF  
HETEROLOGOUS GENES

(iv) NUMBER OF SEQUENCES: 2

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25 (A) ADDRESSEE: Arnold, White & Durkee

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(vi) COMPUTER READABLE FORM:

(A) MEDIUM TYPE: Floppy disk

(B) COMPUTER: IBM PC compatible

35 (C) OPERATING SYSTEM: PC-DOS/MS-DOS, ASCII

(D) SOFTWARE: PatentIn Release #1.0, Version  
#1.25

- 91 -

(vii) CURRENT APPLICATION DATA:

- (A) APPLICATION NUMBER: Unknown
- (B) FILING DATE: Concurrently herewith
- (C) CLASSIFICATION: Unknown

5

(viii) PRIOR APPLICATION DATA:

- (A) APPLICATION NUMBER: SN 08/326,772
- (B) FILING DATE: 18 OCTOBER 1994
- (C) CLASSIFICATION: 1804

10

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- (A) TELEPHONE: 512-418-3000
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- (C) TELEX: 79-0924

20

(2) INFORMATION FOR SEQ ID NO:1:

(i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 213 base pairs
- (B) TYPE: nucleic acid
- (C) STRANDEDNESS: single
- (D) TOPOLOGY: linear

25

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## (xi) SEQUENCE DESCRIPTION: SEQ ID NO:1:

	GAAACCGATT	CGCCCCCTTA	TAACATATTGT	CAGATAACGT	TCTGACGGTT	50						
	GTGTAAAC	ATG	GCG	CCT	CAT	TCT	GTA	GTT	GGA	GTT	AAT	93
5	Met	Ala	Pro	His	Ser	Ser	Val	Val	Gly	Val	Asn	
	1					5					10	

	ATG	AAA	AAA	TTT	TAT	AGC	TGT	CTT	CCT	GTC	TTT	TTA	CTG	ATC	135
	Met	Lys	Lys	Phe	Tyr	Ser	Cys	Leu	Pro	Val	Phe	Leu	Leu	Ile	
10								15		20		25			

	GGC	TGT	GCT	CCT	GAC	TCT	TAT	ACA	CAA	GTA	GCG	TCC	TGG	ACG	177
	Gly	Cys	Ala	Pro	Asp	Ser	Tyr	Thr	Gln	Val	Ala	Ser	Trp	Thr	
15									30		35				

	GAA	CCT	TTC	CCG	TTT	TGC	CCT	GTT	CTG	GAA	AAC	CGG	213
	Glu	Pro	Phe	Pro	Leu	Cys	Pro	Val	Leu	Glu	Asn	Arg	
20								40		45		50	

(2) INFORMATION FOR SEQ ID NO:2:

(i) SEQUENCE CHARACTERISTICS:

(A) LENGTH: 387 base pairs

- 93 -

- (B) TYPE: nucleic acid
- (C) STRANDEDNESS: single
- (D) TOPOLOGY: linear

5 (xi) SEQUENCE DESCRIPTION: SEQ ID NO:2:

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10 TAAATCTAG	CGAGGCCCTT	ACTAAGCTTG	CCCTTCCGC	CGTTGTCTATA	150
ATCGGTTATG	GCATGCCATT	TTATTTCTT	TCTCTGGTTC	TGAAATCCAT	200
15 CCCTGGCGGT	GTTGCTATG	CAGTCTGGTC	GGGACTCGGC	GTCGTCTAA	250
TTACAGCCAT	TGCCTGTTG	CTTCATGGGC	AAAAGCTTGA	TGGGTGGGGC	300
TTTGTAGGTA	TGGGGCTCAT	AGCTGACTCT	TATACACAAAG	ATGCCCTGT	350
20 GACGGAACCT	TTCCCCCTTT	GCCCTGTTCT	GGAAAC		387

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CLAIMS:

1. An *in vivo* method of inducing antigen-specific antibodies comprising oral administration of *Salmonella typhimurium* or *E. coli* transformed with DNA encoding the antigen and a surface exportation DNA and allowing sufficient time for development of an immune response to the antigen.

10

2. The method of claim 1 wherein the surface exportation DNA is SEQ ID NO:1 or a sequence substantially homologous to SEQ ID NO:1.

15

3. The method of claim 1 wherein the antigen is cholera toxin B subunit.

20

4. The method of claim 1 wherein the antigen is influenza hemagglutin or influenza neuraminidase.

25

5. The method of claim 1 wherein the antigen is a human immunodeficiency virus  $\Delta$ gp160, gp120, gp41, or gp24.

30

6. The method of claim 1 wherein the antigen is a 52 kDa or 68 kDa influenza virus hemagglutinin, a 62 kDa human immunodeficiency virus gp120/gp41, or a 32 kDa CtxB fusion protein.

35

7. A method of transporting a protein to the outer surface membrane of a bacterial cell, comprising:

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fusing a DNA encoding cholera toxin B subunit,  
influenza hemagglutinin, influenza  
neuraminidase, human immunodeficiency virus  
Δgp160, gp120, gp41, or gp24, or rickettsial  
5 outer membrane p190 protein with DNA encoding a  
surface exportation protein;

transforming an *E. coli* or *Salmonella* with the fused  
DNA; and

10 culturing the *E. coli* or *Salmonella* to express said  
protein at or within the outer membrane of said  
bacterial cell.

15 8. A recombinant DNA comprising DNA that is identical  
to or homologous with the DNA of SEQ ID NO:1 fused with a  
DNA encoding an immunogenic protein.

20 9. A recombinant DNA comprising DNA that is identical  
or homologous with the DNA of SEQ ID NO:2 fused with a  
DNA encoding an immunogenic protein.

25 10. The recombinant DNA of claim 8 or claim 9 wherein  
the immunogenic protein is a cholera toxin B subunit.

30 11. The recombinant DNA of claim 8 or claim 9 wherein  
the immunogenic protein is a human immunodeficiency virus  
Δgp160, gp120, gp41, or gp24 protein.

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12. The recombinant DNA of claim 8 or claim 9 wherein the immunogenic protein is influenza hemagglutinin or influenza neuraminidase.

5

13. The recombinant DNA of claim 8 or 9 wherein the immunogenic protein is a 52 kDa or 68 kDa influenza virus hemagglutinin, 62 kDa human immunodeficiency virus gp120/gp41 or 32 kDa CtxB fusion protein.

10

14. A pharmaceutical composition comprising *Salmonella* or *E. coli* transformed with the recombinant DNA of claim 8 or claim 9 in a pharmaceutically acceptable vehicle.

15

15. The pharmaceutical composition of claim 14 wherein expressed immunogenic protein is associated with the outer membrane surface of the *Salmonella* or *E. coli*.

20

16. The pharmaceutical composition of claim 14 wherein expressed immunogenic protein is associated with the periplasm of the *Salmonella* or *E. coli*.

25

17. The pharmaceutical composition of claim 15 or claim 16 wherein the immunogenic protein is cholera toxin B subunit, influenza hemagglutinin, influenza neuraminidase, HIV Agp160, gp120, gp41, or gp24 protein, or rickettsial outer membrane p190 protein.

30  
35 18. A method of *in vivo* induction of cholera toxin B subunit protective antibodies comprising:

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5 orally administering to an animal a recombinant *Salmonella* or *E. coli* that periplasmically or outer membrane expresses cholera toxin B subunit wherein cholera toxin B subunit specific antibodies are produced in response to the administration.

10 19. The method of claim 18 wherein the recombinant *Salmonella* or *E. coli* harbors DNA that includes DNA encoding cholera toxin subunit B fused with the DNA of SEQ ID NO:1 or SEQ ID NO:2 or substantially homologous DNA sequence.

15 20. The method of claim 1 wherein the antigen is rickettsial outer membrane p190.

20 21. The recombinant DNA of claim 8 or claim 9 wherein the immunogenic protein is a rickettsial outer membrane p190 protein.

25 22. A pharmaceutical composition comprising outer membrane fragments of *Salmonella* or *E. coli* transformed with the recombinant DNA of claim 8 or claim 9 in a pharmaceutically acceptable vehicle, wherein said fragments have an immunogenic protein associated therewith.

30 23. The pharmaceutical composition of claim 22 wherein said immunogenic protein is cholera toxin B subunit, influenza hemagglutinin, influenza neuraminidase, human

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immunodeficiency virus  $\Delta$ gp160, gp120, gp41, or gp24 protein, or rickettsial outer membrane p190 protein.

5 24. The pharmaceutical composition of claim 22 wherein expressed immunogenic protein is located in the periplasm of the *Salmonella* or *E. coli*.

10 25. A method of *in vivo* induction of rickettsial outer membrane p190 protective antibodies comprising:

15 orally administering to an animal a recombinant *Salmonella* or *E. coli* that periplasmically or outer membrane expresses rickettsial outer membrane p190 antigen wherein rickettsial outer membrane p190-specific antibodies are produced in response to the administration.

20 26. The method of claim 25 wherein the recombinant *Salmonella* or *E. coli* harbors DNA that includes DNA encoding rickettsial outer membrane p190 fused with the DNA of SEQ ID NO:1 or SEQ ID NO:2 or substantially 25 homologous DNA sequence.

27. A method of *in vivo* induction of influenza hemagglutinin protective antibodies comprising:

30 orally administering to an animal a recombinant *Salmonella* or *E. coli* that periplasmically or outer membrane expresses influenza hemagglutinin antigen wherein influenza 35 hemagglutinin-specific antibodies are produced in response to the administration.

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28. The method of claim 27 wherein the recombinant *Salmonella* or *E. coli* harbors DNA that includes DNA encoding influenza hemagglutinin fused with the DNA of SEQ ID NO:1 or SEQ ID NO:2 or substantially homologous 5 DNA sequence.

29. A method of *in vivo* induction of influenza neuraminidase protective antibodies comprising:

10 orally administering to an animal a recombinant *Salmonella* or *E. coli* that periplasmically or outer membrane expresses influenza neuraminidase antigen wherein influenza 15 neuraminidase-specific antibodies are produced in response to the administration.

20 30. The method of claim 30 wherein the recombinant *Salmonella* or *E. coli* harbors DNA that includes DNA encoding influenza neuraminidase fused with the DNA of SEQ ID NO:1 or SEQ ID NO:2 or substantially homologous DNA sequence.

25 31. A method of *in vivo* induction of human immunodeficiency virus  $\Delta$ gp160, gp120, gp41, or gp24 protective antibodies comprising:

30 orally administering to an animal a recombinant *Salmonella* or *E. coli* that periplasmically or outer membrane expresses HIV  $\Delta$ gp160, gp120, gp41, or gp24 antigen wherein HIV-specific 35 antibodies are produced in response to the administration.

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32. The method of claim 31 wherein the recombinant *Salmonella* or *E. coli* harbors DNA that includes DNA encoding human immunodeficiency virus  $\Delta$ gp160, gp120, gp41, or gp24 protein fused with the DNA of SEQ ID NO:1 or SEQ ID NO:2 or substantially homologous DNA sequence.

5  
33. The pharmaceutical composition of claim 14 or claim 22 further comprising an adjuvant.

10

34. A kit comprising in packaged combination:

15 a carrier means adapted to receive a plurality of container means in close confinement therewith;

20 a first container means including an attenuated *Salmonella* or *E. coli* transformed with the DNA of SEQ ID NO:1 or SEQ ID NO:2 fused with an immunogenic protein; and

25 a second container means including a pharmaceutically acceptable vehicle for admixing with said transformed *Salmonella* or *E. coli*.

35. A kit comprising in packaged combination:

30 a carrier means adapted to receive a plurality of container means in close confinement therewith;

35 a first container means including outer membrane fragments of *Salmonella* or *E. coli* transformed with the DNA of SEQ ID NO: 1 or SEQ ID NO:2 fused with an immunogenic protein; and

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a second container means including a pharmaceutically acceptable vehicle for admixing with said membrane fragments.

5

36. The kit of claim 34 or 35 wherein the immunogenic protein is cholera toxin B subunit, human immunodeficiency virus Agp160, human immunodeficiency virus gp120, human immunodeficiency virus gp41, human immunodeficiency virus gp24 protein, influenza hemagglutinin, influenza neuraminidase, or rickettsial outer membrane p190 protein.

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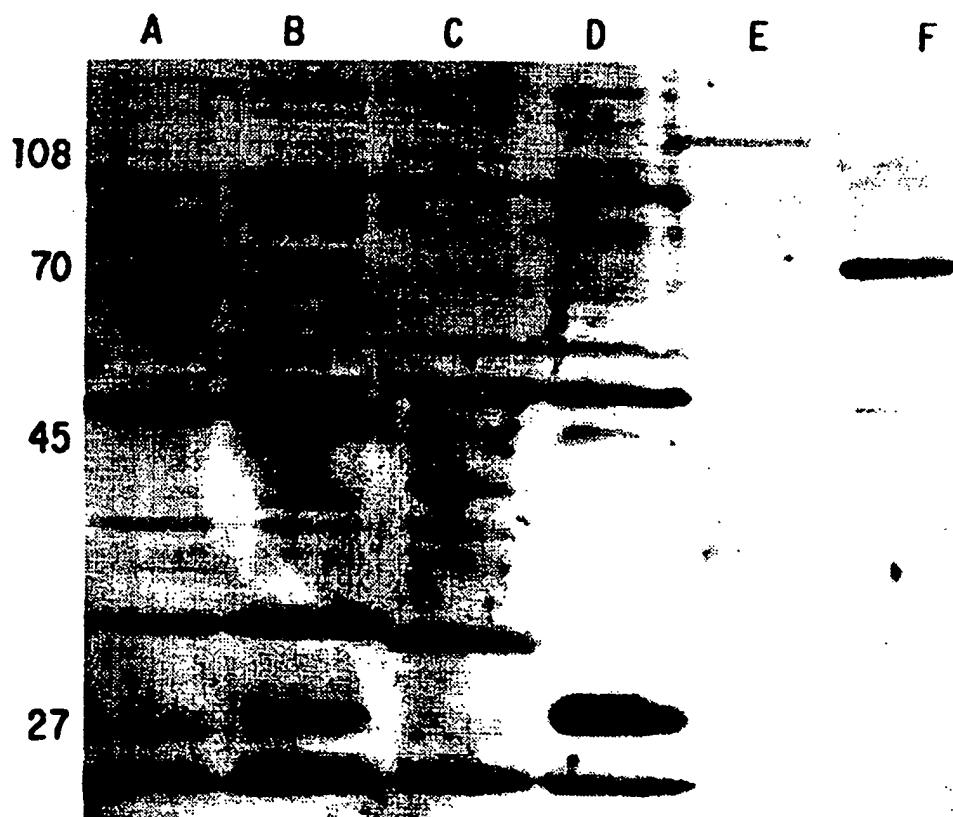


FIG. 1

FIG. 2

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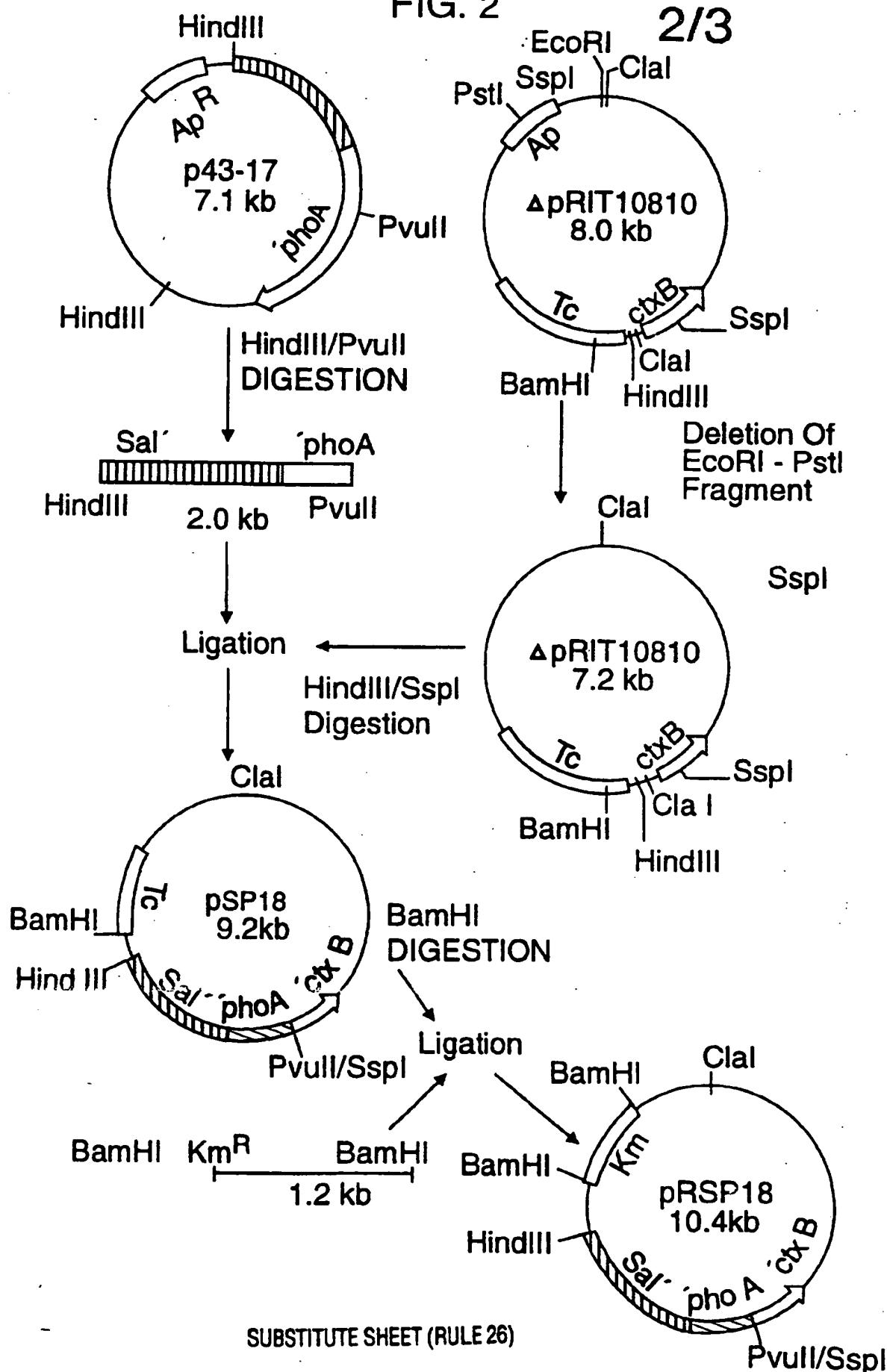
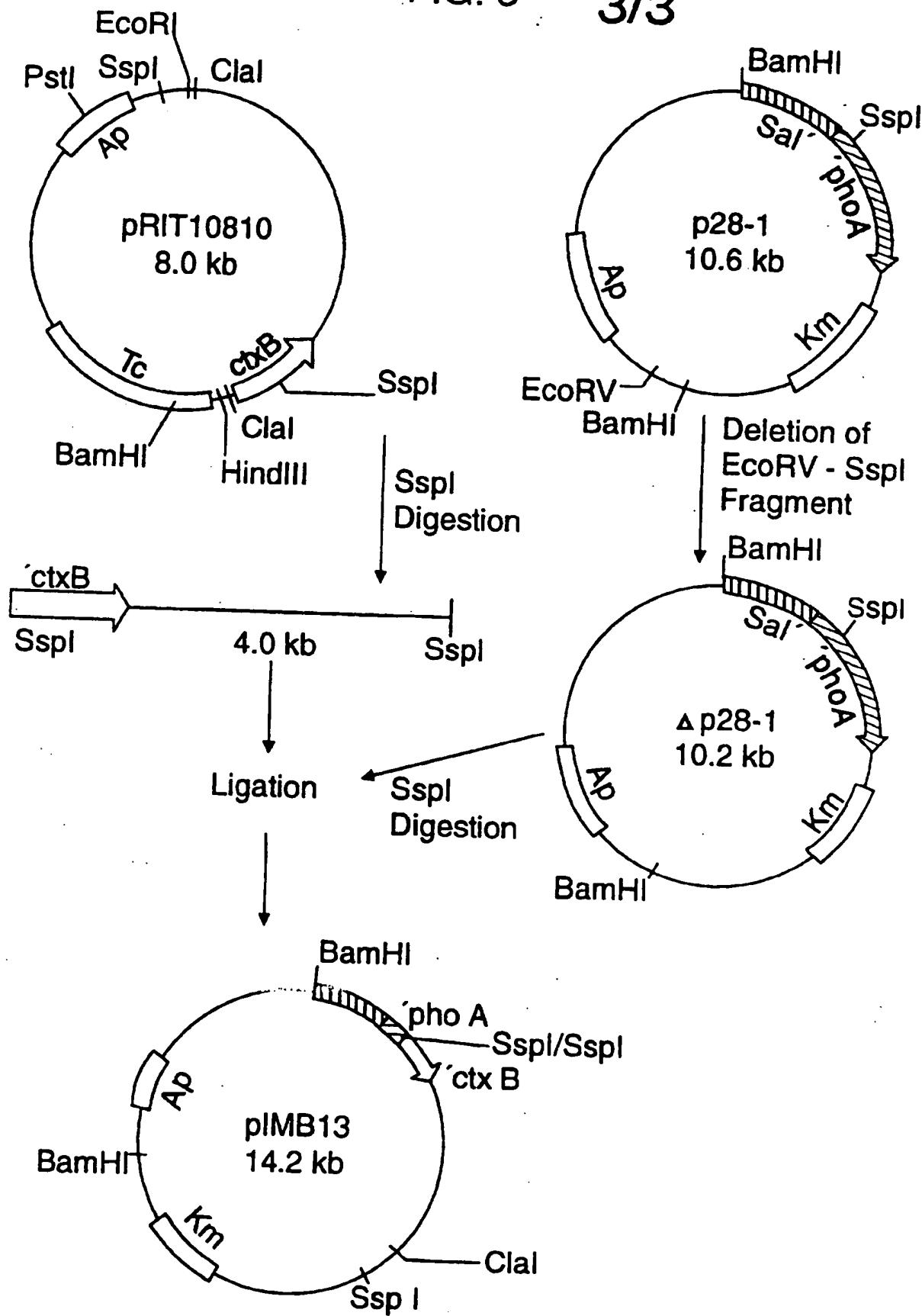


FIG. 3  
3/3

## INTERNATIONAL SEARCH REPORT

International application No.  
PCT/US95/13333

## A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :Please See Extra Sheet.

US CL :Please See Extra Sheet.

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 424/93.1, 184.1, 186.1, 190.1, 207.1, 208.1; 435/69.1, 69.7; 536/23.1

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

Medline

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X ----	WO 93/10246 (BOARD OF REGENTS, THE UNIVERSITY OF TEXAS SYSTEM) see entire document, especially pages 5, 8, 9, 14, 15, 16, 34, 39, 40, 42.	1-3, 5-11, 13-19, 22-24, 31-36 -----
Y		4, 12, 20, 21, 25-30
X	US A. 5, 098, 998 (MEKALONAS ET AL) 24 March 1992, see columns 3, 9, 10.	14-18, 22-24, 33

Further documents are listed in the continuation of Box C.  See patent family annex.

Special categories of cited documents:	
"A"	document defining the general state of the art which is not considered to be of particular relevance
"B"	earlier document published on or after the international filing date
"L"	document which may throw doubt on priority claim(s) or which is cited to establish the publication date of another citation or other special reasons (as specified)
"O"	document referring to an oral disclosure, use, exhibition or other means
"P"	document published prior to the international filing date but later than the priority date claimed
"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to extend or refine principle or theory underlying the invention
"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"a"	document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
09 FEBRUARY 1996	16 FEB 1996
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231	Authorized officer H. P. Sidberry
Facsimile No. (703) 305-3230	Telephone No. (703) 308-0196

# INTERNATIONAL SEARCH REPORT

International application No.

PCT/US95/13333

## Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This international report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1.  Claims Nos.:  
because they relate to subject matter not required to be searched by this Authority, namely:
  
2.  Claims Nos.:  
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
  
3.  Claims Nos.:  
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

## Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

Please See Extra Sheet.

1.  As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2.  As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
3.  As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
  
4.  No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

The additional search fees were accompanied by the applicant's protest.

No protest accompanied the payment of additional search fees.

**INTERNATIONAL SEARCH REPORT**

International application N .  
PCT/US95/13333

**A. CLASSIFICATION OF SUBJECT MATTER:**

IPC (6):

**A61K 39/12, 39/106; C12N/15/62, 9/16, 15/31, 1/21; C07H 21/04; C12P 21/04****A. CLASSIFICATION OF SUBJECT MATTER:**

US CL :

**424/93.1, 184.1, 186.1, 190.1, 207.1, 208.1; 435/69.1, 69.7; 536/23.1****BOX II. OBSERVATIONS WHERE UNITY OF INVENTION WAS LACKING**

This ISA found multiple inventions as follows:

This application contains the following inventions or groups of inventions which are not so linked as to form a single inventive concept under PCT Rule 13.1. In order for all inventions to be examined, the appropriate additional examination fees must be paid.

Group I, claim(s) 1-7, 14-21, 25-33, drawn to in vivo method of inducing antigen-specific antibodies by giving *Salmonella* or *E. coli* transformed with DNA encoding antigens: cholera toxin B subunit; influenza hemagglutin or influenza neuraminidase; HIV; rickettsial outer membrane p190 and a surface exportation DNA, method of exporting a protein to the bacterial membrane surface classified in Classes 424 and 435 subclasses 93.2 and 93.1, 192.1, 197.1, 200.1 and 69.3, 69.7

Group II, claim(s) 8-13, drawn to recombinant DNA fused to DNA encoding an immunogenic protein, classified in Class 536 subclass 23.4.

Group III, claim(s) 22-24, 35, 36, drawn to pharmaceutical compositions comprised of membrane fragments of *Salmonella* or *E. coli* transformed with the DNA encoding the exportation protein associated with an antigen, classified in Class 424, subclasses 184.1, 186.1, 188.1, 190.1, 210.1, 207.1, 208.1

This application contains claims directed to more than one species of the generic invention. These species are deemed to lack Unity of Invention because they are not so linked as to form a single inventive concept under PCT Rule 13.1. In order for more than one species to be examined, the appropriate additional examination fees must be paid. The species are as follows:

cholera toxin subunit B (claims 3, 6, 7, 10, 13, 17, 18, 19, 23, 24, 36); influenzae hemagglutin or neuraminidase (claims 4, 6, 7, 12, 17, 23, 27, 28, 29, 30, 36); HIV antigens (claims 5, 7, 11, 17, 23, 31, 32, 36); rickettsial outer membrane protein (claims 7, 17, 20, 21, 23, 25, 26, 36).

The following claims are generic: claims 1, 2, 8, 9, 14, 15, 16, 22, 24, 33, 34, 35.

The inventions listed as Groups I, II and III do not relate to a single inventive concept under PCT Rule 13.1 because, under PCT Rule 13.2, they lack the same or corresponding special technical features for the following reasons: The claims of these three groups are directed to inventions which are linked by a special technical feature. However, the technical feature which links the inventions is known in the art as exemplified by the US Patent 5 098 998, which discloses using an exportation protein to express cholera toxin.

The species listed above do not relate to a single inventive concept under PCT Rule 13.1 because, under PCT Rule 13.2, the species lack the same or corresponding special technical features for the following reasons: the exportation protein is used with species of: cholera toxin subunit B; influenzae hemagglutin or neuraminidase; HIV antigens and rickettsial outer membrane protein which are considered physicochemically, structurally, antigenically and functionally distinct.